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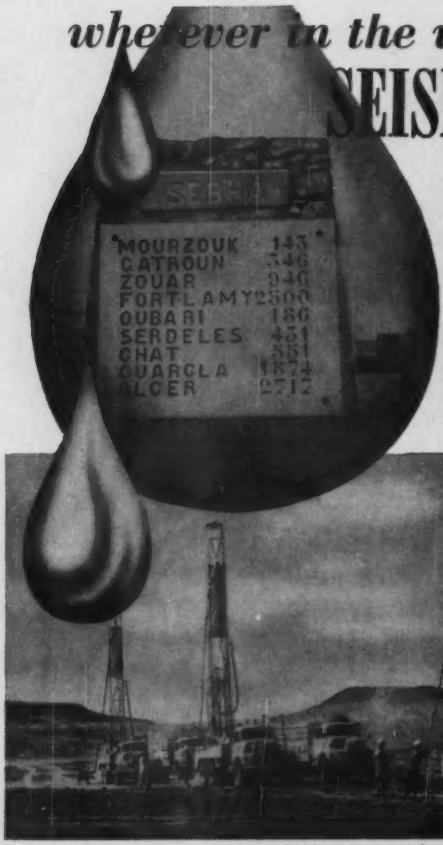


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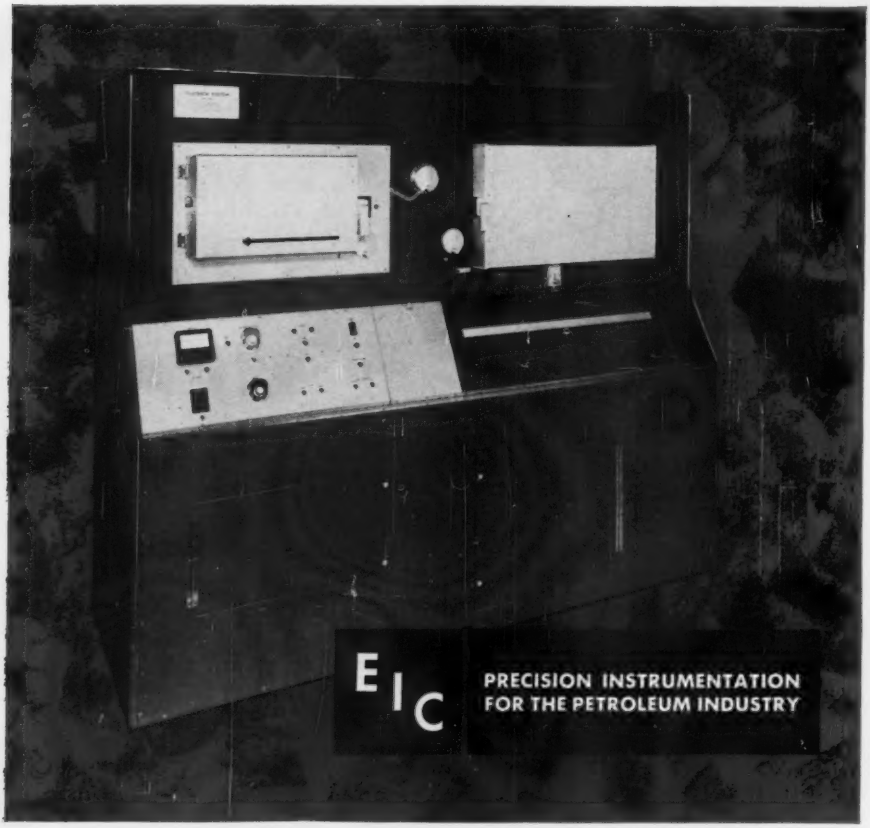


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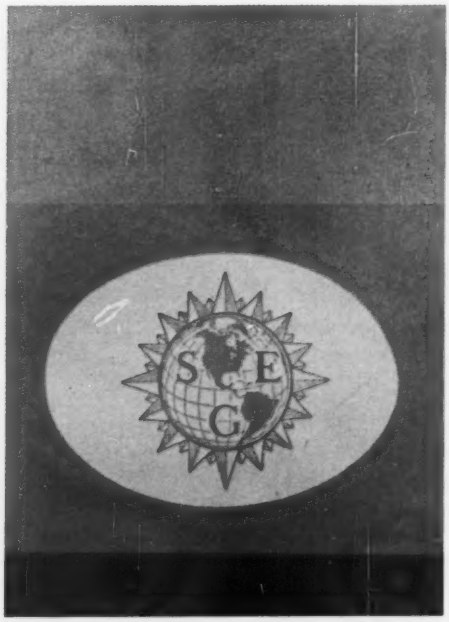


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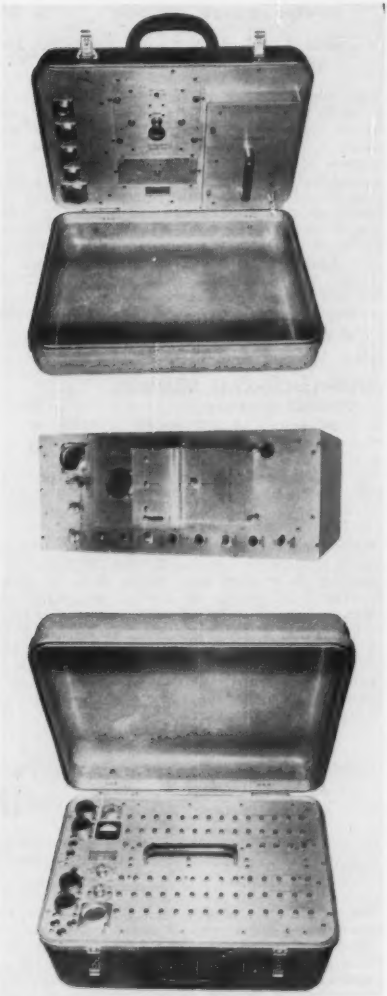

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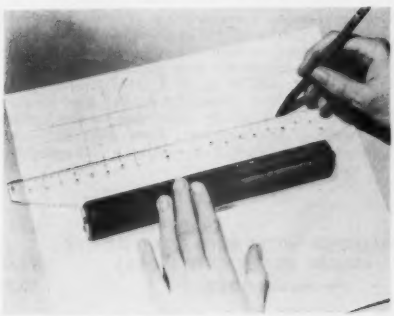

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*(Continued on page 31)*

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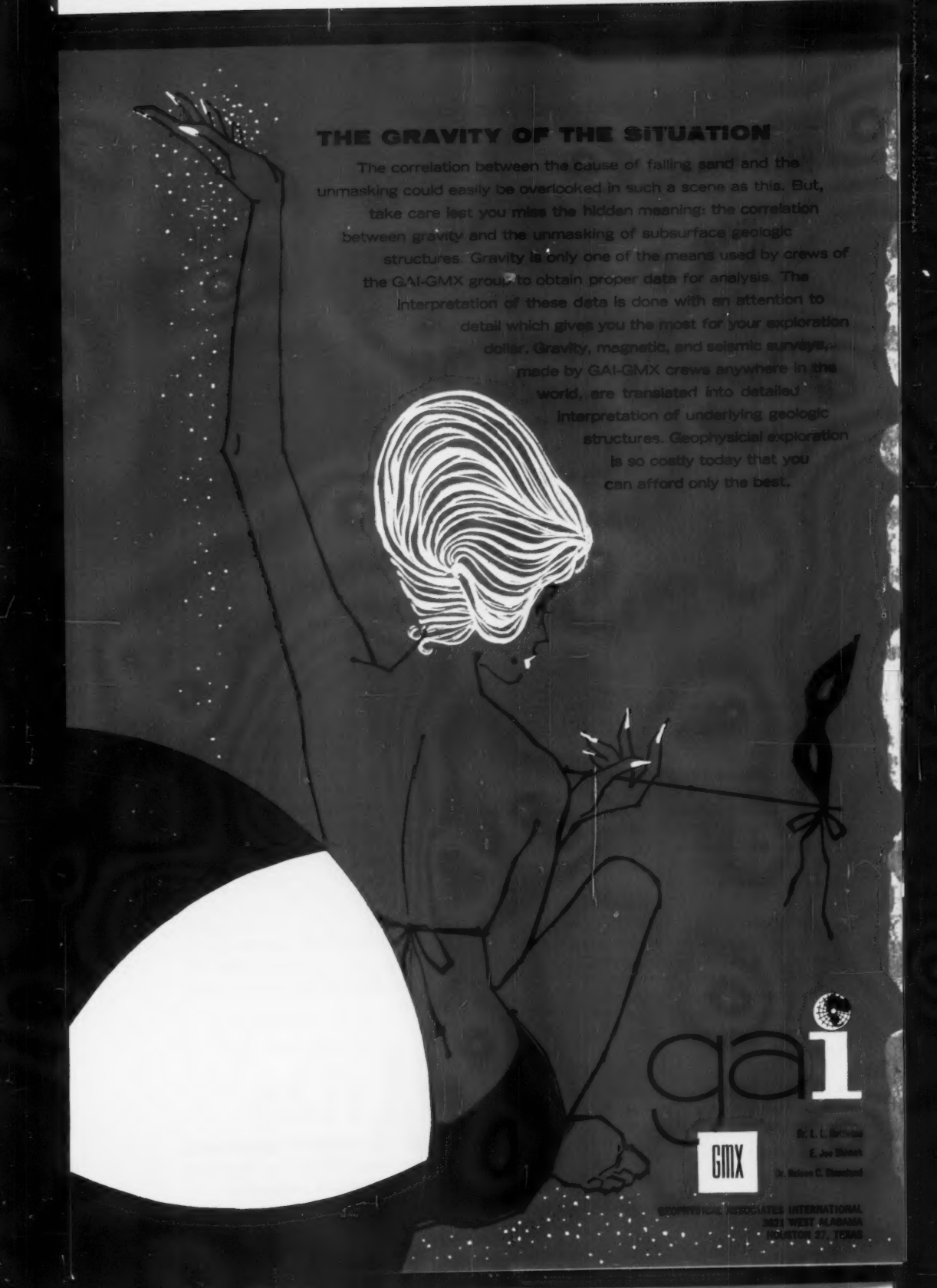
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VOLUME XXV DECEMBER, 1960 NUMBER 6

# GEOPHYSICS

## A CASE HISTORY OF THE BRONTE (ELLENBURGER) AND RAWLINGS FIELDS, COKE COUNTY, TEXAS*

ROLLIN E. PHIPPS†

ABSTRACT

The North Bronte Area interested Lion Oil Company on the basis of surface, isopachous and magnetic studies. A large block of acreage was acquired and explored by the seismograph. A well was drilled on the shooting and proved the shooting to be reliable. A velocity survey in this well, however, indicated that the map of the reflective event identified as Ellenburger was actually Caddo. Additional shooting was done before the Lion No. 1 Edwards, the discovery well of the Bronte (Ellenburger) Field, was drilled. The discovery well of the Rawlings Field was drilled by Humble on seismic information. There are eight producing zones in these fields. Shooting costs and permit fees have remained amazingly constant through the years.

### INTRODUCTION

The Bronte (Ellenburger) and Rawlings Fields are located in the eastern portion of Coke County, Texas, on the Eastern Shelf area of the Midland Basin. At present the Bronte Field represents the southernmost area of Cambrian production of the Cambrian Trend of West-Central Texas. Cambrian production was first established on this trend in the Bronte and Rawlings Fields. The Concho Arch is to the south and the axis of the Bend Arch is located 60 miles to the east. (See Figure 1.)

### GEOPHYSICAL PROCEDURES

In 1946, Lion was offered a block of more than 11,000 acres. A surface structure map, made by L. G. Welch in 1928, was submitted along with the acreage. A. E. Barnes was Lion's District Geologist in Abilene at that time. A surface anomaly was indicated in the area and after additional study of the regional subsurface structure of the Permian with special emphasis on Permian Isopachous intervals, Lion took the acreage. Mr. Barnes was convinced that the Permian Isopachous intervals were important and should indicate thinning or draping over, or the presence of, pre-Permian structures. A magnetic survey seemed to indicate a positive area substantiating the surface and subsurface feature. An Ellenberger subsurface study indicated nothing more than a structural "nosing" to the west across the block.

* Presented at the 13th Annual Midwestern SEG Meeting, Shreveport, La., April 5, 1960. Manuscript received by the Editor May 26, 1960.

† Lion Oil Company, Midland, Texas.

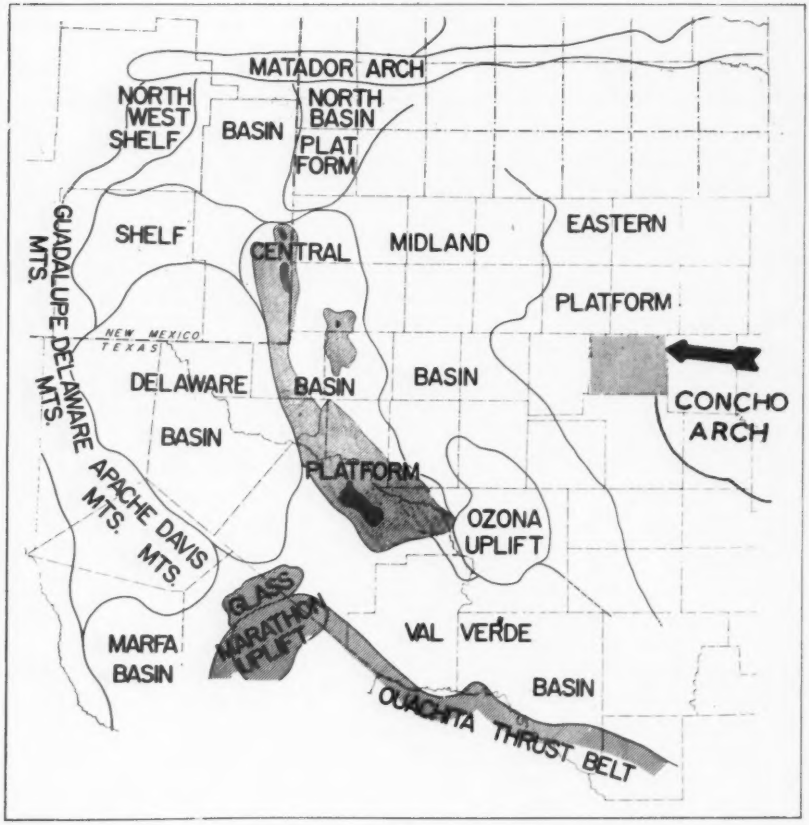



FIG. 1. Geologic Provinces West Texas & Southeast New Mexico.

The initial seismic work was done from January to June, 1950. A single velocity survey was available in the Union No. 1 McCutchen, approximately 4 miles southwest of the surveyed area.

Figure 2 shows a portion of the seismic program conducted at this time. Actually, the Bronte (Ellenburger) and Rawlings Fields are contiguous. The discovery well of the Bronte (Ellenburger) Field, the Lion No. 1 Edwards in the southeast quarter of Section 365, was completed February 11, 1953. The Rawlings Field discovery, the Humble No. 1 Rawlings in the southeast quarter of Section 397, was spudded in March 1952. The Bronte (Ellenburger) produces from the Ellenburger (Cambro-Ordovician), while the Rawlings Field produces from one Cambrian and six Pennsylvanian horizons. The Fort Chadbourne Field

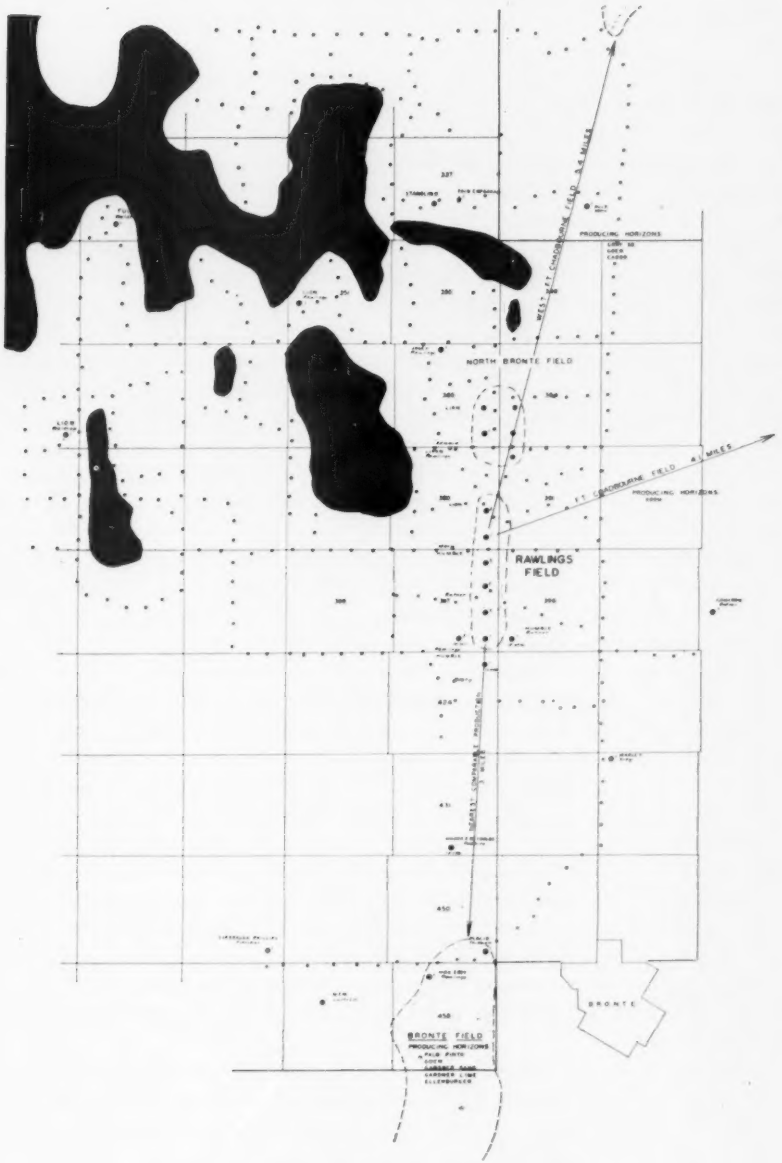



FIG. 2. Coke County, Texas, North Bronte Area.

is 4½ miles northeast. It is a westward-dipping monoclinal structure and produces from the Lower Pennsylvanian (Odom and Caddo). The West Fort Chadbourne Field is 5½ miles north and is Pennsylvanian production associated with the Fort Chadbourne fault system. The Bronte Field is 3 miles south and is another multi-pay structural field.

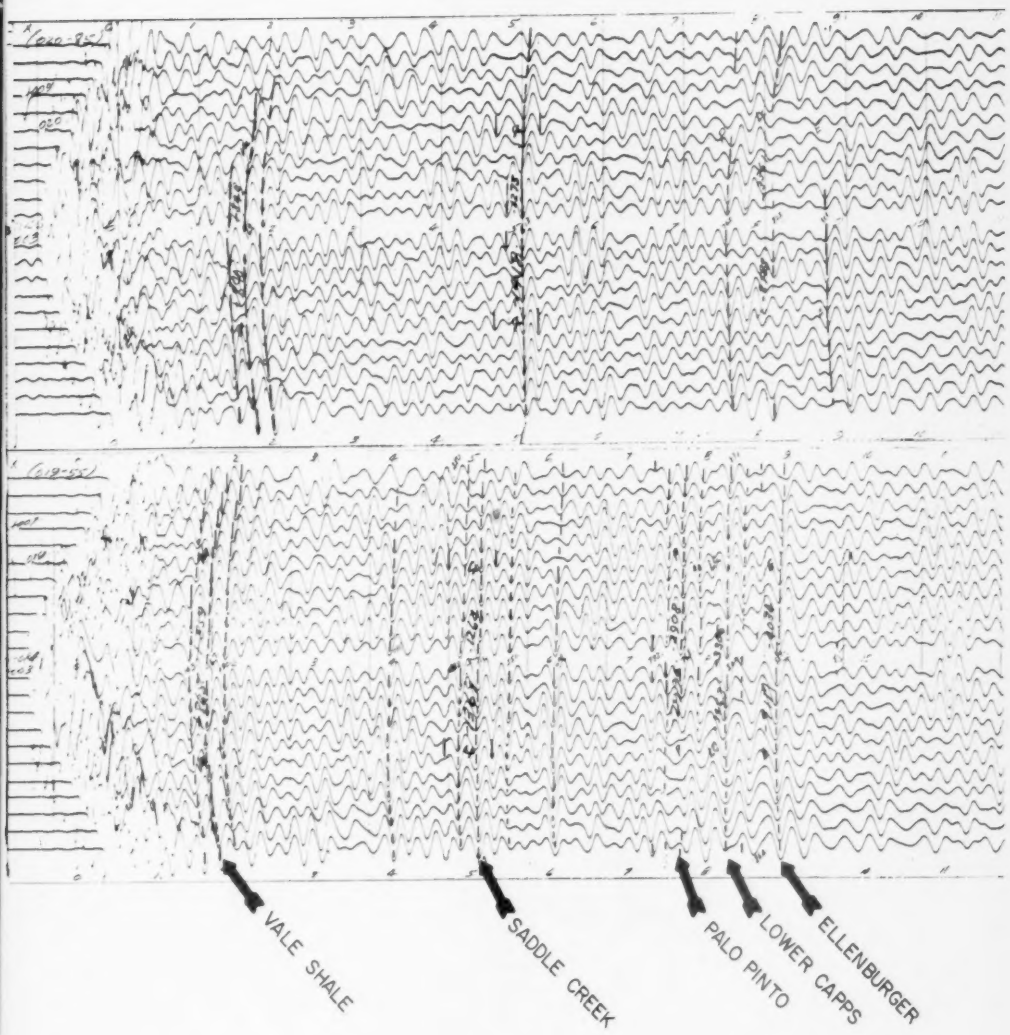
The topography in most of the area was characterized by steep-sided buttes capped by Edwards Limestone. The buttes are shown on Figure 2, and only one shotpoint is located on a butte. Record quality was poor on the buttes, as shown on Figure 3. These records were shot less than 1,000 ft apart. The record at the top was shot on top of a 200-ft butte, and the lower one in the valley below. You will notice that the deeper energy is much better on the lower record. Needless to say, the crew stayed in the valleys. Tomlinson Geophysical Company shot 570 holes at an average depth of 78 ft, using 30 pounds of powder per shot, during the initial program. Five geophones per group were used, and slight "mixing" was deemed necessary. Permits cost $10.00 per hole. By computing the records to a horizontal datum plane, a general tilting of the seismic data to the southeast was noted. Rather than apply a velocity gradient, since so little velocity information was available, the records were recomputed and referred to the shot depth. This was effective in correcting the mis-ties.

Good reflective events were tentatively identified as Vale shale, Saddle Creek lime, Palo Pinto lime, Lower Capps lime and Ellenburger dolomite. (See Correlation Chart, Figure 4.) The event identified as Palo Pinto (Lower Canyon) offered a very persistent continuous reflection in the southern portion of the area but deteriorated rapidly to the north. This deterioration is probably associated with a lime and reef buildup. The most persistent event on the records was the Lower Capps. Several leads were developed by the shooting. Probably due to a mis-correlation, an Ellenburger map, prepared by the geological staff while the shooting was in progress, showed the presently producing area as an anomaly on the *down* side of a fault. For this reason a rather small localized feature to the west was chosen as the best prospect. The Lion No. 1 Waldrop was drilled on this feature in October, 1950. It was located approximately 4 miles west of the Bronte (Ellenburger) Field, and northeast of the McCutchen (Swastika sand) Field. (See Figure 2.) The well checked the shooting at the Lower Capps (Upper Strawn) horizon within 75 ft, but the prospective Swastika sand of the Lower Cisco (Upper Pennsylvanian) was not present. A velocity survey was run in the Waldrop, and it was discovered that the event previously identified as the Ellenburger was actually Caddo.

The results of the initial shooting in the field area are shown on Figure 5. This map was contoured on a reflective event identified as the Lower Capps, Lower Pennsylvanian in age. Actually the time horizon mapped is probably slightly above the Capps within the Upper Strawn.

The importance of the isopach interval was recognized, and the crew was

*(Text continued on page 1174)*


VALE SHALE
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PALO PINTO
LOWER CAPPS
ELLENBURGER

FIG. 3.

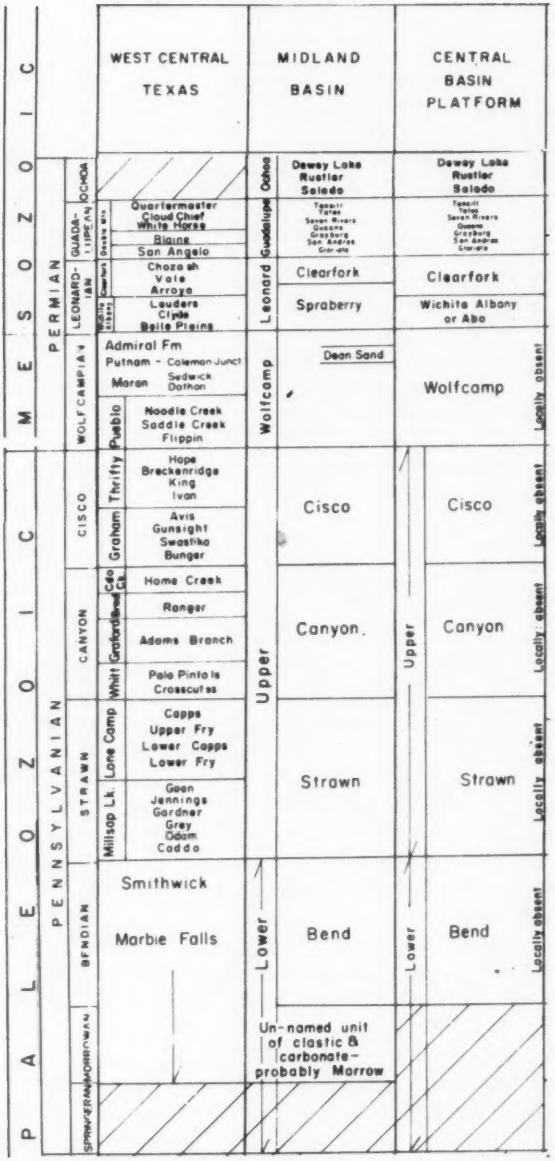


FIG. 4. Stratigraphic relationship of various units of the Permian and Pennsylvanian in West Texas.

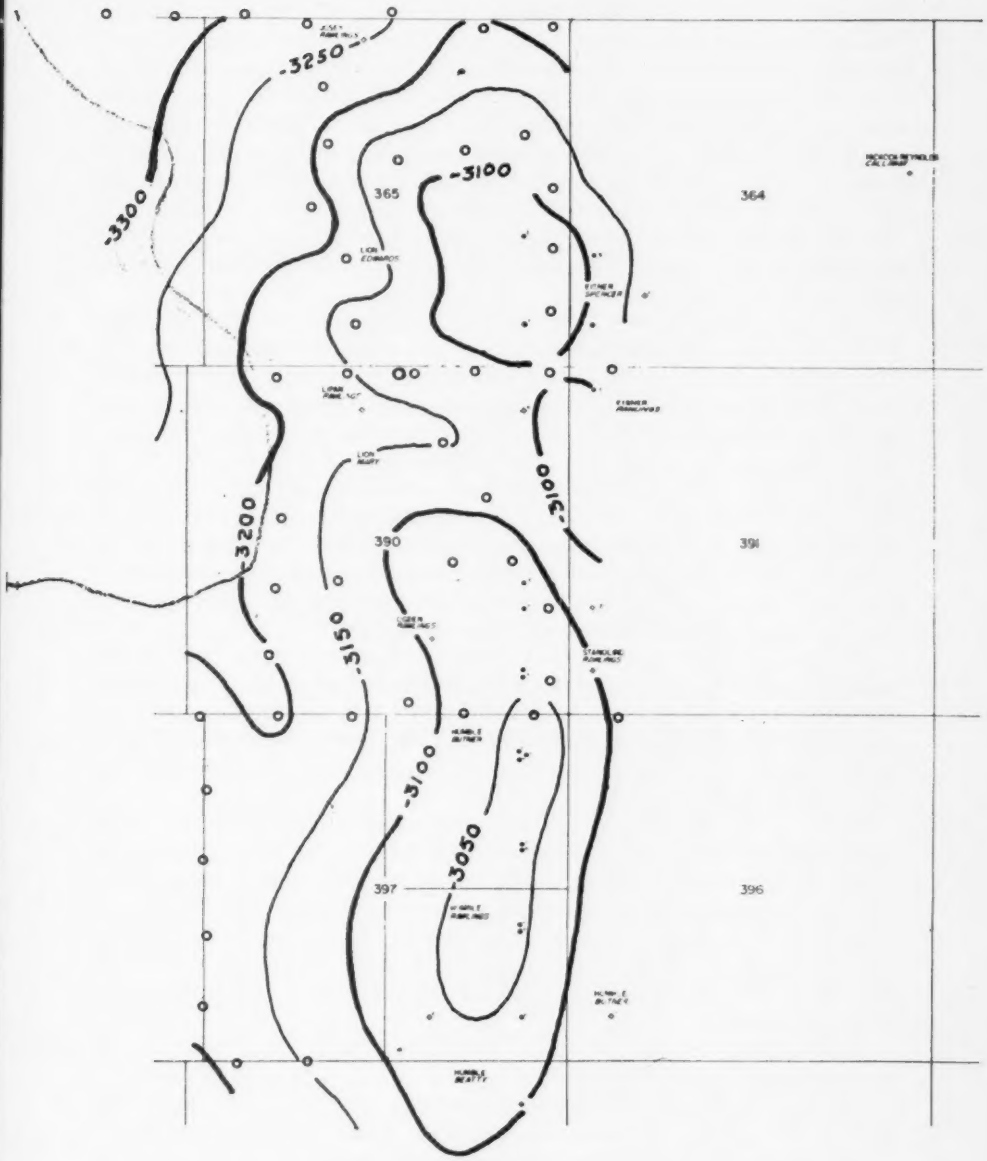


FIG. 5. North Bronte, Rawlings Field, Coke County, Texas. Lower Capps.

requested to present the Saddle Creek to Lower Capps map shown on Figure 6. The discovery well on the Bronte (Ellenburger) Field is shown in the southeast quarter of Section 365. The separation of the two thin areas was proved by a dry hole in the northeast quarter of Section 390, plugged and abandoned July 7, 1953. A Lower Capps to Ellenburger Isopach was also prepared (Figure 7). The thin area is still persistent to the south; however, the thin area in Section 365 on Figure 6 was not apparent on this interval. The inferred thickening to the east in Section 397 is more abrupt than shown here since it is probably associated with faulting. The Ellenburger is eroded above the top of the Rawlings structure; but since the reflective event mapped was above the Ellenburger, this is a valid indication of Lower Pennsylvanian structure.

The same crew was sent back for some additional seismic lines in May, 1951. The results of the additional lines across the now productive area are shown on Figure 8. The new line across Section 397 showed approximately 100 ft of additional relief. The steep east dip, or down-to-the east faulting, on the east side of the field was indicated. Actually, the seismic interpretation would preclude anything but faulting. An offset well in the southwest quarter of Section 396, drilled by Humble in October of 1952, was 900 ft low to the discovery well. This was no surprise to Lion personnel, due to our seismic interpretation. Humble has credited the seismograph with the discovery of the Rawlings Field, the Bronte Field to the south, and the Fort Chadbourne to the north-east. As previously mentioned, the Fort Chadbourne Field is a monoclinal structure and was found due to a velocity anomaly which indicated a pseudo high closure.

Figure 9 is a record section (A-A′) shot by Humble in April, 1948. These records were shot with 1,000-foot to 1,800-foot spreads, four geophones per group. Forty-pound charges were shot at approximately 120 ft. An uphole survey indicated a 9,500 ft/sec computing velocity, and the records were corrected to a 1,600-ft datum plane. This cross-section runs east-west approximately bisecting the Rawlings Field. (See Figure 8.)

Figure 10 is a record section (B-B′) which closely duplicates the location of the previous section. These records were shot for Lion by Tomlinson Geophysical Service in 1950. The method of shooting was described previously. These record sections are shown merely to indicate the record quality in the area. The present Humble and Lion supervisors would have preferred less mixing or compositing, but these records found oil. The shooting cost averaged $121.00 per location, or $13,800.00 per month, including explosives, permits, drilling and all other miscellaneous charges.

Lion acquired gravity coverage in 1955 because of the "reef play" in the western portion of Coke County. Figure 11 shows the area as presently interpreted from Exploration Survey's derivative data. The lines of traverse of the gravity crew and the derivative data points are shown on this map. It will be noted that even with the knowledge of the anomaly, the gravity indication is very

(*Text continued on page 1178*)

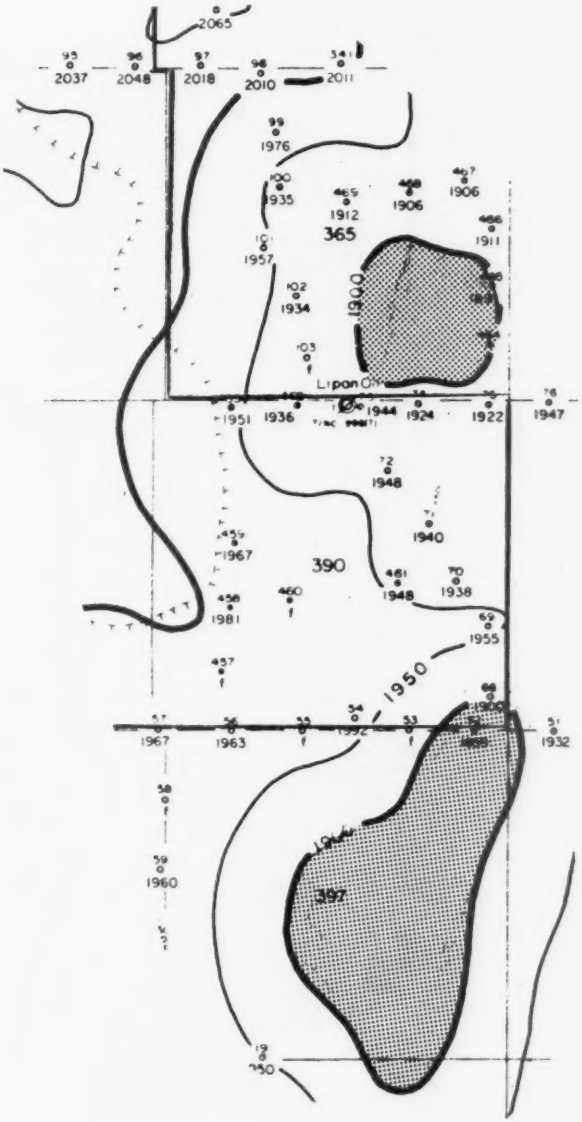


FIG. 6. Saddle Creek—Lower Capps Isopach.

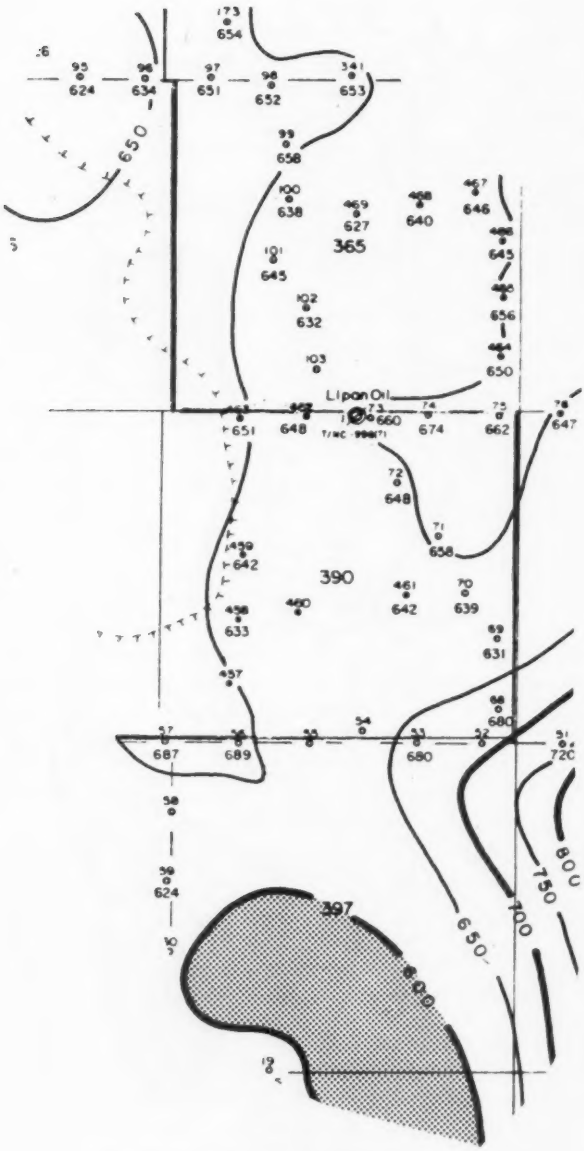


FIG. 7. Lower Capps—Ellenburger Isopach.

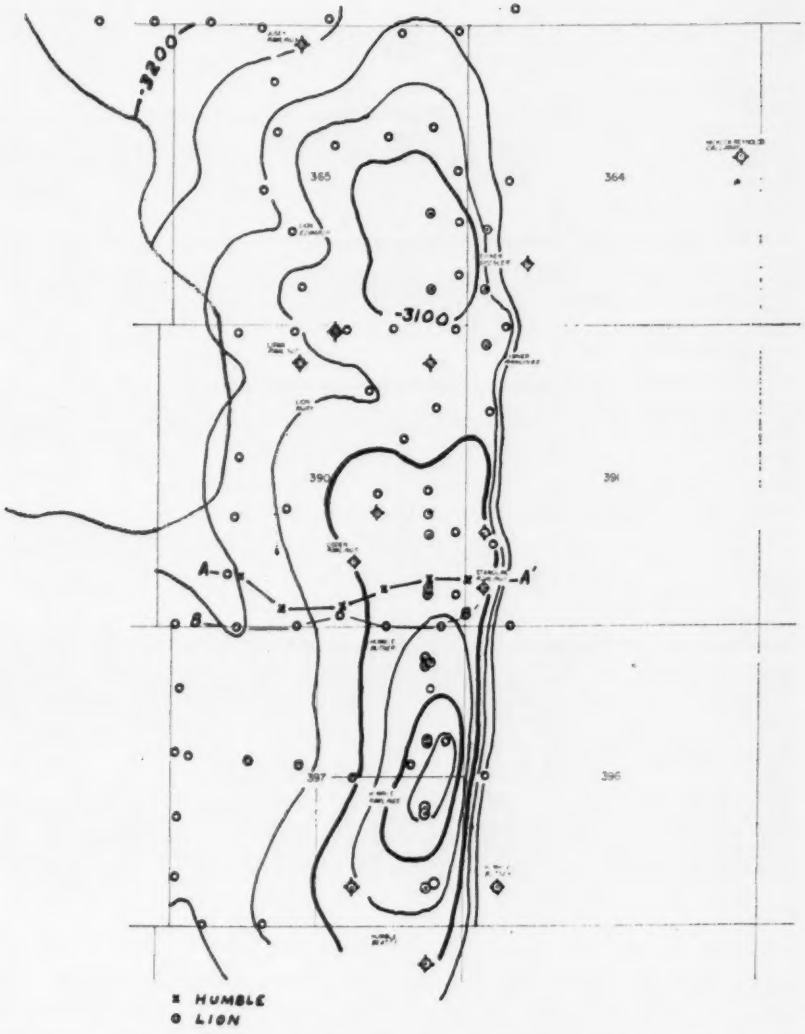


FIG. 8. North Bronte, Rawlings Field, Coke County, Texas. Lower Capps.

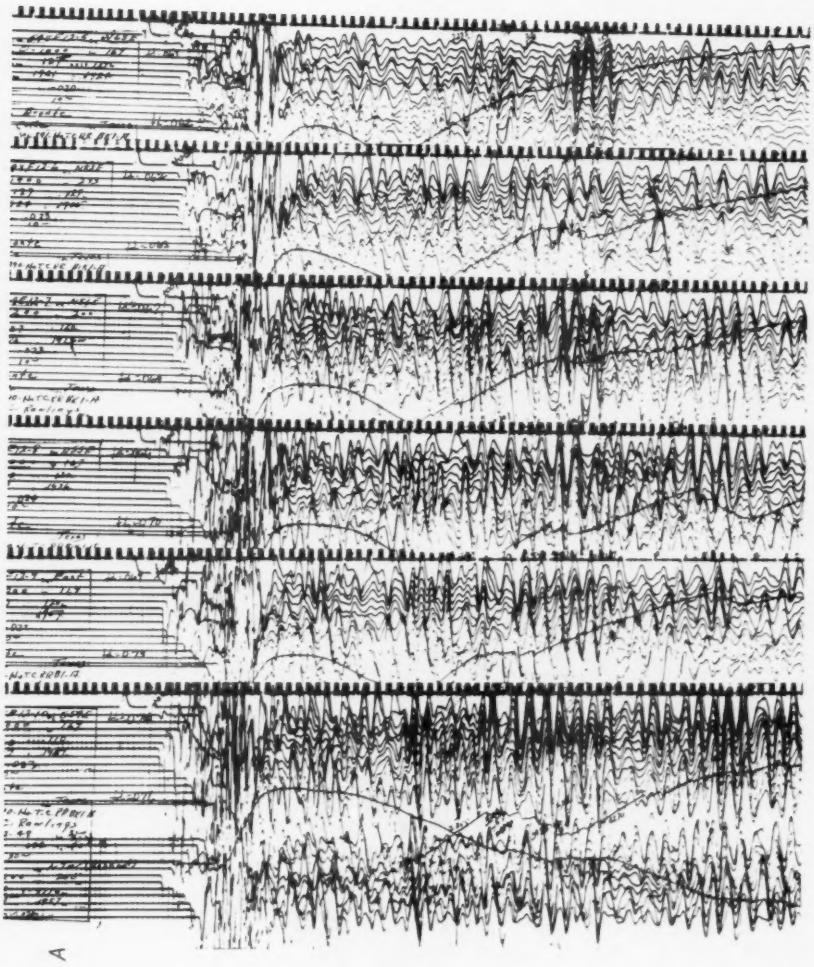

FIG. 9.

subtle. This certainly demonstrates the need for detailed gravity control in an area such as this. Notice the zero gravity line. This is often indicative of faulting (all faults must be associated with a zero derivative contour, according to theory). Some substantiation is added to the seismic fault.

Figure 12 is a revised composite of the seismic and subsurface interpretation on the Gardner sand (Strawn) after S. D. Ayers. This horizon is approximately 300 ft below the lower Capps horizon, previously shown. Note the steep dip on

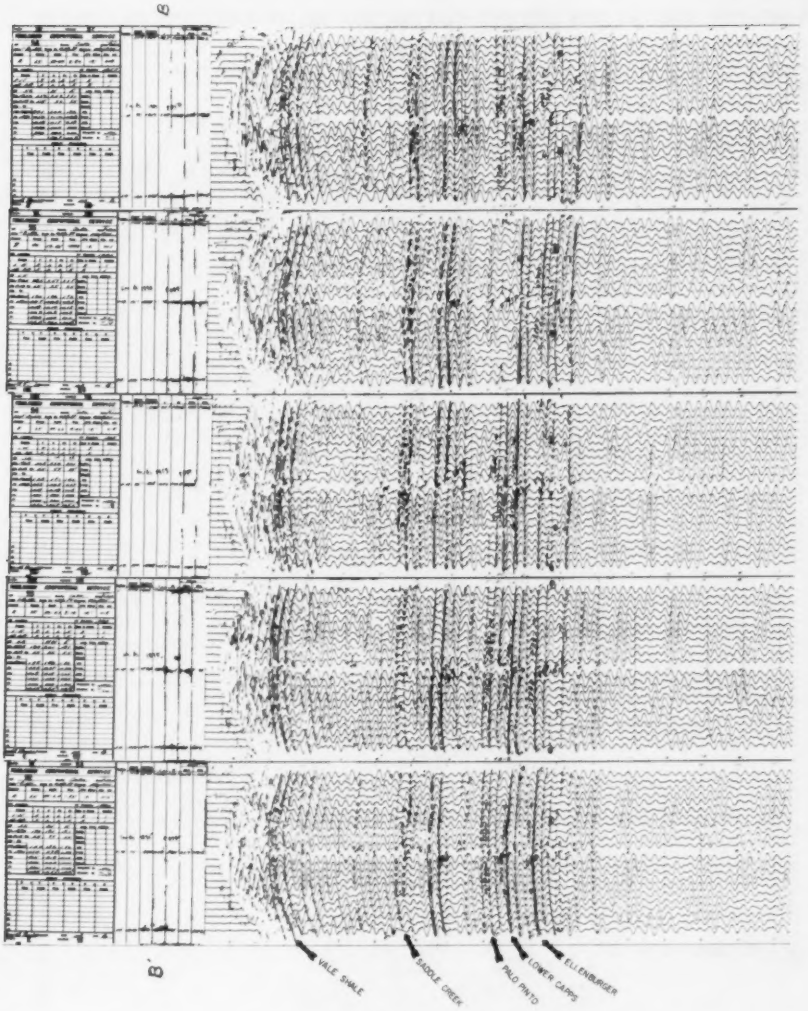


FIG. 10.

the east side of the field. Figure 13 shows the present producing area of the Bronte (Ellenburger) and Rawlings Fields. This map demonstrates the narrow structural feature of the area. In May of 1953 all production in this area, previously identified as "North Bronte," officially became classified as the "Rawlings" Fields.

(*Text continued on page 1183*)

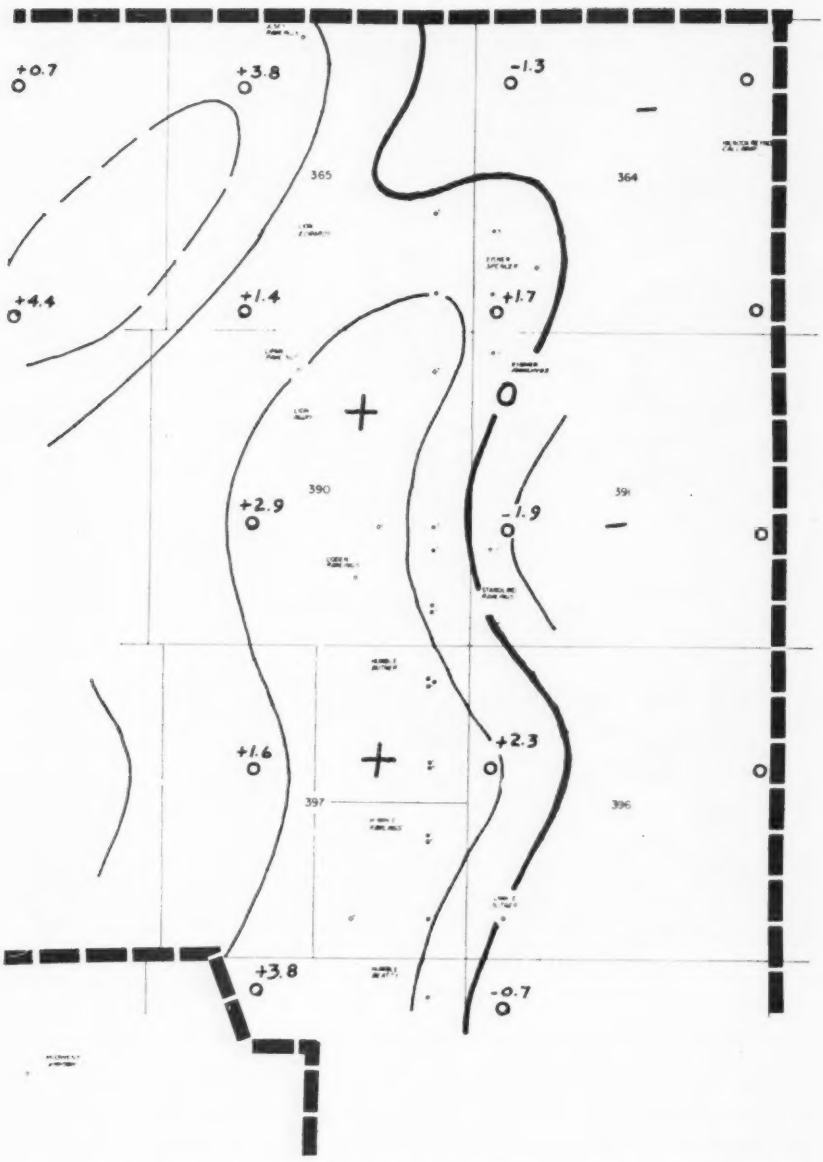


FIG. 11. North Bronte, Rawlings Field, Coke County, Texas. Gravity.

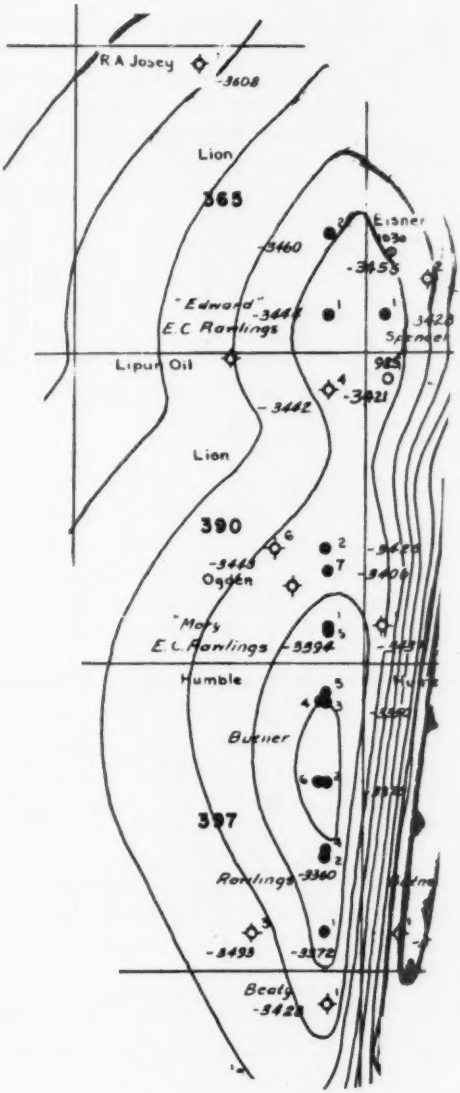


FIG. 12. Gardner Sand Horizon after S. D. Ayres.

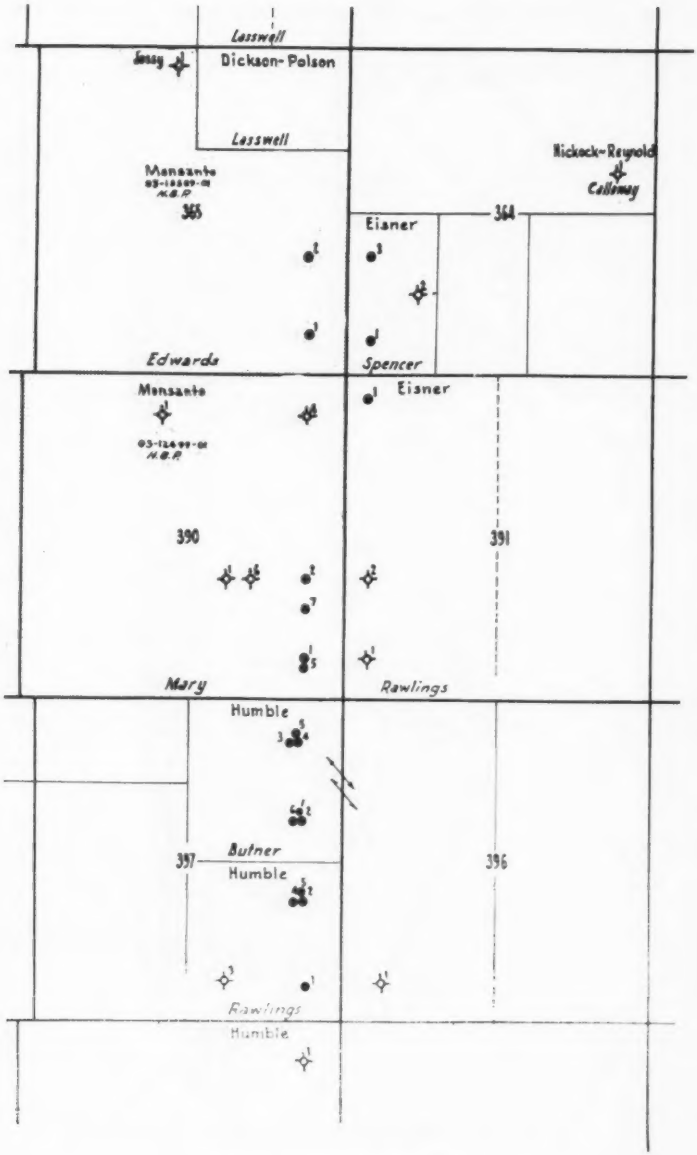


FIG. 13. Present producing area.

An interesting and refreshing sidelight to the history of this seismic program is a comparison with present conditions in the area. A contract crew which shot in the vicinity last year reports that permits are still $10.00 to $15.00 per hole and the average cost per shot hole is $119.00. Midwest Oil Corporation reports that a program which was conducted in 1958, in an area just north of the subject area, had identical shooting conditions. The best record was produced with a 20-pound charge at about 100 ft, 1,320-ft spreads with six geophones per group. However, they had to pay up to $25.00 for permits. Midwest Oil Corporation conducted a seismic program west of the Rawlings Field in 1954. Permits were $25.00 per hole, and they shot 10-pound charges at 60-ft hole depths. Two-hundred feet of high velocity limestone build-up caused the drilling of the Midwest No. 1 Simpson, shown on Figure 7, 1 mile southwest of the Rawlings Field. The consistency of the shooting cost is probably due to a rapid exploration and "cooling" off of the area. In 1948, 100 crew weeks were recorded in Coke County, while 1950 showed only 65. By 1952 only 22 crew weeks were expended, and this figure dwindled to 18 in 1958.

## CONCLUSION

These fields were found independently by seismograph crews working for Humble and Lion. They have now produced over 1,500,000 barrels of oil from 19 wells. The initial shooting picture had to be detailed as much as topography would allow. Gravity could have indicated the lead; however, more detailed work would have been necessary to delineate the prospect area. The area has been a victim of rapid exploration and equally rapid "cooling off" period.

## ACKNOWLEDGMENTS

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National Oil Scouts and Landmen's Association Yearbooks, 1948, 1950, 1952, 1958.

GEOPHYSICS, VOL. XXV, NO. 6 (DECEMBER, 1960), PP. 1184–1194, 6 FIGS.

# NUMERICAL RESISTIVITY INTERPRETATION: GENERAL INHOMOGENEITY*

K. VOZOFF†

## ABSTRACT

A linear approximation is developed for the equation of conduction in a medium where resistivity is an arbitrary function of $x$, $y$, and $z$. This is applied by assuming the earth to be subdivided into small, homogeneous blocks of arbitrary resistivity. Under this approximation, the apparent resistivity is just the sum of the effects of the individual blocks. The equations are linear, and surface apparent resistivity data can be inverted to yield block resistivities.

The quality of the approximation has been checked by comparison with model measurements in two situations: remote current source (telluric method), and local current source (resistivity method). It was found that the results are satisfactory provided that the proper type of expression is used for the effect of the resistivity contrast of each block.

The ultimate objective of this work is to enable a geophysicist to obtain a complete interpretation of a dc resistivity survey with a minimum of subjective adjusting. Ultimately, these techniques will probably develop to a stage where measurements will come in from the field, be put directly into a computer, and an interpretation will come out that uses not only all of the measurements to their full accuracy, but also any additional information which may be available, such as that from physical property measurements and geological observations. To some extent this is already being done with seismic data. The one-dimensional and two-dimensional resistivity problems have already been carried to the computer stage (Alfano, 1959; Ness, 1959; Vozoff, 1958). The following discussion applies to the three-dimensional problem.

## INTRODUCTION

In order to do this problem, we replace the real, nonuniform earth with a model earth made up of small, uniform blocks. Then we can approximate any distribution of conductivity of interest by making the blocks small enough and by assigning to each of them an appropriate conductivity. We first set up the equation of conduction for this model earth, which allows us to predict the surface apparent resistivities for any assumed distribution of conductivity (forward problem). This was first done by Stevenson (1934) and the next section follows Stevenson quite closely. If we take the first two terms of the series, we have an approximation which is linear in that the effect of each block is added to give the net effect (no interaction). We are able to write a set of linear equations relating block conductivities with surface apparent resistivities. It is then a

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† Department of Physics, University of Alberta, Edmonton, Alberta.

straightforward problem of working backward by matrix manipulation to find conductivities from apparent resistivity measurements (inverse problem).

The last part of the work concerns some model measurements made to check the quality of the approximation, and an example of an actual solution is shown.

## EQUATION OF CONDUCTION

Considering a conduction medium and direct current, at a point $P$ where the conductivity is $\sigma_P$ and the vector current density is $J_P$, we have

$$E_P = -\nabla\phi_P = J_P/\sigma_P$$

which defines the field at that point. Taking the divergence, we obtain

$$\nabla\cdot J_P = -\nabla\sigma_P\cdot\nabla\phi_P - \sigma_P\nabla^2\phi_P.$$

Rearranging, we obtain

$$\nabla^2\phi_P = -(\nabla\cdot J_P + \nabla\sigma_P\cdot\nabla\phi_P)/\sigma_P$$

which is similar to Poisson's equation. We solve for $\phi_P$ by integrating sources over all space,

$$\phi_P = \frac{1}{4\pi}\iiint_{-\infty}^{\infty}\frac{\nabla\cdot J_R + \nabla\sigma_R\cdot\nabla\phi_R}{\sigma_R r_{RP}}\,dR,$$

$$dR = dr_1 dr_2 dr_3 \qquad r_{RP}^2 = (r_1 - p_1)^2 + (r_2 - p_2)^2 + (r_3 - p_3)^2.$$

For a source of current $I$ located at point $Q$, the $\nabla\cdot J$ term is zero everywhere except at $Q$, so the first term integrates simply, and we have, assuming that $\sigma_P = \sigma_Q$,

$$\phi_P = \frac{I}{4\pi\sigma_P r_{PQ}} + \frac{1}{4\pi}\iiint\frac{\nabla\sigma_R\cdot\nabla\phi_R}{\sigma_R r_{RP}}\,dR,$$

$$r_{PQ}^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2 + (p_3 - q_3)^2.$$

The first term is the well-known formula for potential in a uniform material of conductivity $\sigma_P$ and the second term is a correction because of the fact that the material is not uniform. This correction term is the potential due to charge distributions which are induced wherever conductivity is changing. The size of the charge distribution is proportional to the gradient of the conductivity and to the strength of the electric field at that point. It is maintained by the current. If $\sigma$ is constant, $\nabla\sigma = 0$ and the second term drops out. In the case of a half space with both $P$ and $Q$ on the surface, both terms are doubled and we have equation (1). We can call the first term the undisturbed potential, and the second, the correction potential.

$$\phi_P = \frac{I}{2\pi\sigma_P r_{PQ}} + \frac{1}{2\pi}\iiint\frac{\nabla\sigma_R\cdot\nabla\phi_R}{\sigma_R r_{RP}}\,dR \qquad (1)$$

$$= \phi_P{}^0 + \phi_P'.$$

The assumption that $\sigma_P = \sigma_Q$ requires that there be a thin surface layer of uniform conductivity.

## THE APPROXIMATION

Equation (1) would be a fairly routine integral equation for $\phi$ in terms of $\sigma$ were it not for the $\nabla\phi$ under the integral. As it is, an exact solution in a finite number of terms cannot be written down.

What is commonly done in a case like this is to approximate $\phi_R$ under the integral by the first of the two terms, i.e. for purposes of finding $\nabla\phi_R$ we write

$$\phi_R \simeq \frac{I}{2\pi\sigma_P r_{RQ}}$$

and take the gradient

$$\nabla\phi_R \simeq -\frac{I}{2\pi\sigma_P r_{RQ}^3}\, r_{QR}$$

$$r_{QR} = (r_1 - q_1)\hat{\imath} + (r_2 - q_2)\hat{\jmath} + (r_3 - q_3)\hat{k}.$$

Substituting into the integral for $\phi_P'$, we obtain

$$\phi_P' \simeq -\frac{I}{4\pi^2\sigma_P}\iiint \frac{\nabla S_R \cdot r_{QR}}{r_{RP} r_{QR}^3}\, dR$$

where

$$S_R = \ln \sigma_R.$$

The complete approximation for potential becomes equation (2).

$$\phi_P \simeq \frac{I}{2\pi\sigma_P}\left[\frac{1}{r_{PQ}} - \frac{1}{2\pi}\iiint \frac{\nabla S_R \cdot r_{QR}}{r_{RP} r_{QR}^3}\, dR\right]. \tag{2}$$

The process of successive approximation could continue ad infinitum, but it is of interest to see how good this approximation is.

If we go back to the model made up of uniform cubes, the integrand in equation (2) will be zero except at the interfaces between cubes, since within any cube $\sigma$ is constant. Assume that the cubes are to be oriented along our $r_1$, $r_2$, $r_3$ axes, and that we are making measurements along, say, the $r_2$ direction. For a surface $A_1$ (see Figure 1) perpendicular to the $r_1$ axis, whose coordinates are $(a_1, r_2, r_3)$,

$$\nabla S_R = \hat{\imath}\frac{dS_R}{dr_1}\,\delta(A_1),$$

$$r_{QR} = (a - q_1)\hat{\imath} + (r_2 - q_2)\hat{\jmath} + (r_3 - q_3)\hat{k}.$$

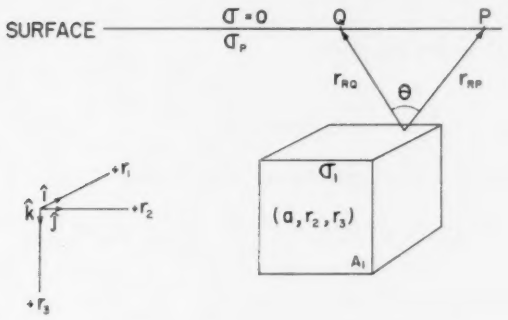


FIG. 1. Coordinate System and Physical Situation.

The second term in equation (2), $\phi_P'$, becomes

$$\phi_P' \simeq \frac{I}{4\pi^2\sigma_P} \iiint \frac{(a-q_1)\,\dfrac{dS_R}{dr_1}\,\delta(A_1)\,dr_1 dr_2 dr_3}{[(a-p_1)^2+(r_2-p_2)^2+(r_3-p_3)^2]^{1/2}[(a-q_1)^2+(r_2-q_2)^2+(r_3-q_3)^2]^{3/2}}$$

which integrates to give us a function of conductivity multiplied by a function which depends only on geometry.

$$\begin{aligned}\phi_P' &\simeq \frac{-I\Delta S}{4\pi^2\sigma_P}\,(a-q_1)\iint_{A_1} \frac{dr_2 dr_3}{[(a-p_1)^2+(r_2-p_2)^2+(r_3-p_3)^2]^{1/2}[(a-q_1)^2+(r_2-q_2)^2+(r_3-q_3)^2]^{3/2}} \\ &\simeq \frac{+I\Delta S}{4\pi^2\sigma_P}\,g_1(P),\end{aligned} \tag{3}$$

where $\Delta S = \ln(\sigma_2/\sigma_1)$, the change in $\ln\sigma$ at the surface, and $g_1(P)$ represents the geometric contribution of that one surface. For a complete cube there will be one term for each surface,

$$\phi_P' \simeq \frac{I\Delta S \sum g_i(P)}{4\pi^2\sigma_P} = \frac{I\Delta S G(P)}{4\pi^2\sigma_P}.$$

The total potential is given by equation (4) where $G(P)$ is the sum of the effects of the six surfaces of one cube.

$$\phi_P \simeq \phi_P^0 + \frac{I\Delta S}{4\pi^2\sigma_P} G(P). \tag{4}$$

When there are $n$ cubes, we can add up their effects linearly because changes in conductivity enter as the logarithm

$$\phi_P \simeq \phi_P{}^0 + \frac{I}{4\pi^2\sigma_P} \sum_{i=1}^{n} \Delta S_i G_i(P).$$

Since each of $P$ and $Q$ can be anywhere on the surface

$$\phi(P_j, Q_k) \simeq \phi^0(P_j, Q_k) + \frac{I_k}{4\pi^2\sigma_P} \sum_{i=1}^{n} \Delta S_i G_i(P_j, Q_k),$$

or, simplifying notation,

$$\phi_{jk} \simeq \phi_{jk}{}^0 + \frac{I_k}{4\pi^2\sigma_P} \sum_{i=1}^{n} \Delta S_i G_{ijk} \tag{5}$$

which is the most general form of the expression. This is a set of linear equations in $n$ unknowns, the $n$ values of $S_i$. Since we can take readings for as many locations $P_j$ and $Q_k$ as we choose, we can make the total number of readings equal to $n$ and have a completely determined set of equations, or we can make the total number of readings greater than $n$ and have an overdetermined set. In the latter case we can use least squares or some other form of fitting.

## QUALITY OF THE APPROXIMATION

Consider again equation (4), which is the approximate potential at $P$ due to a source at $Q$ when there is one cube ($\sigma_1$) in an otherwise uniform half space($\sigma_P$).

$$\phi_P \simeq \frac{I}{2\pi\sigma_P r_{PQ}} + \frac{I}{4\pi^2\sigma_P} \ln\left(\frac{\sigma_1}{\sigma_P}\right) G(P). \tag{4}$$

Compare this with the expression for a single sphere ($\sigma_1$) in a uniform full space ($\sigma_P$),

$$\phi_P = \frac{I}{4\pi\sigma_P r_{PQ}} + \frac{I}{4\pi\sigma_P}(\sigma_1 - \sigma_P) \sum_{n=1}^{\infty} \frac{n r_1{}^{2n+1} P_n(\cos\theta)}{[n\sigma_1 + (n+1)\sigma_P](r_{RQ} r_{RP})^{3/2}}, \tag{6}$$

where $r_1$ is the radius of the sphere, and $\theta$ is the angle between $r_{RQ}$ and $r_{RP}$ subtended at the center of the sphere. As $\sigma_1$ becomes infinite or zero, equation (6) tends to some finite value, whereas equation (4) tends to plus or minus infinity. The behavior of (4) is contrary to experience, which indicates that once the ratio $\sigma_1/\sigma_P$ exceeds some moderate value, increasing it still further makes no detectable difference in the measured apparent resistivities. Likewise, a decrease in the ratio beyond moderate limits causes no detectable change in measured results.

Assuming that the term $\ln(\sigma_1/\sigma_P)$ of equation (4) could be replaced by a contrast factor of the form

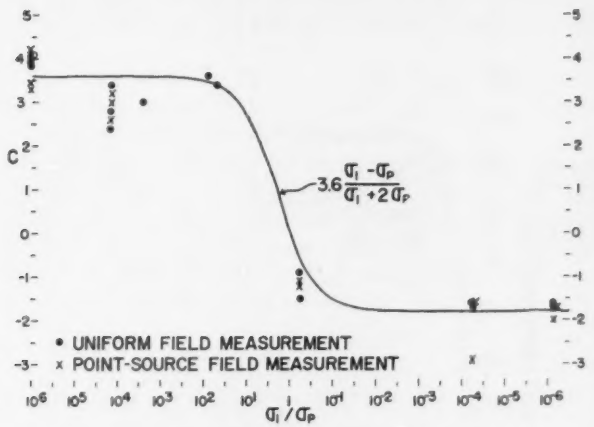


FIG. 2. Variation of $C$ with Conductivity Contrast.

$$c\,\frac{\sigma_1 - \sigma_P}{\sigma_1 + 2\sigma_P} = C \tag{7}$$

a series of model measurements were made to determine empirically the constant $c$. These measurements were made on single blocks of several conductivities in water at two different conductivities. This was done in two ways: with point sources of current, and with uniform current to simulate dc telluric fields. The results are summarized in Figure 2, and indicate that

$$c \simeq 3.6.$$

Replacing equation (4) by equation (8) and using

$$\phi_P \simeq \frac{I}{2\pi\sigma_P r_{PQ}} + \frac{I}{4\pi^2\sigma_P}\left[3.6\,\frac{\sigma_1 - \sigma_P}{\sigma_1 + 2\sigma_P}\right] G(P), \tag{8}$$

$G(P)$ as calculated by the method of equation (3), the effects of several cubes were predicted and compared with measurements. Figures 3 and 4 show two typical examples. The data are shown as percentage difference in apparent resistivity, from that of a uniform medium due to the presence of the cube. Figure 3 is the result in a uniform field. The inset at the right shows the model arrangement to the same horizontal scale as the curves. The traverse line passes over the center of a unit cube whose top surface is at a depth of one-half unit. The measurements were made on a graphite cube in tap water.

Figure 4 is an example of a point-source measurement over the same cube at a depth of one unit. The presentation is the standard one for this type of

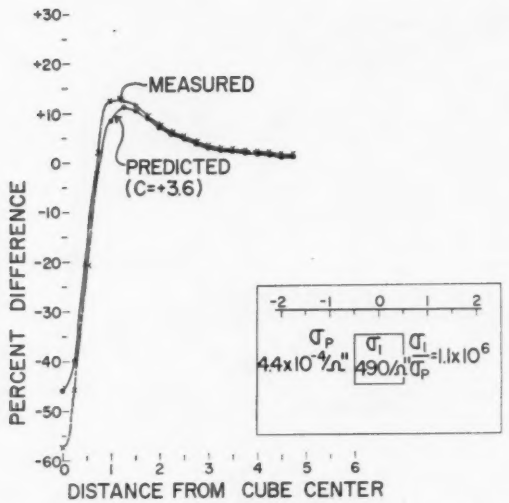


FIG. 3. Telluric Measurement. Percentage difference in field due to a cube.

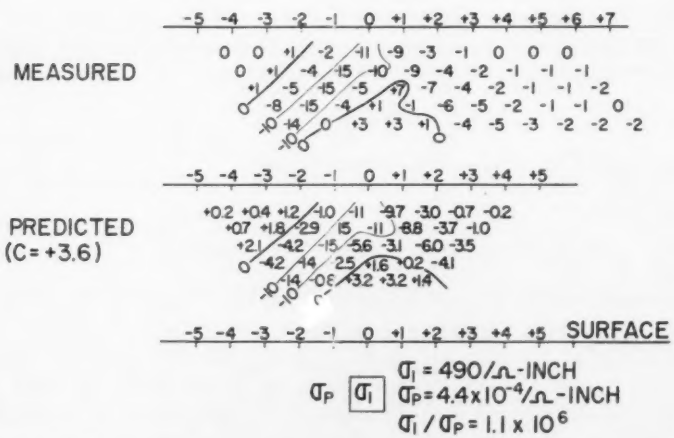


FIG. 4. Apparent Resistivity Measurement. Percentage difference in apparent resistivity due to a cube. Pole-dipole configuration.

measurement (pole-dipole) and is discussed by Marshall and Madden (1959, p. 793).

The solution might be improved by a method of successive approximations. That is, once a solution has been found, calculate a new potential and use this in equation (1). This has not yet been attempted.

Figure 5 is an example of an analysis of model data, using this approach. It is taken from Ness (1959) with the kind permission of the author. In his thesis, Dr. Ness presents several examples of computer analysis of both model and field data, which indicate that the method is successful. The model (dark outline) was approximated by the group of eight smaller blocks shown. Blocks and model were six units long perpendicular to traverse, and the traverse line ran three units

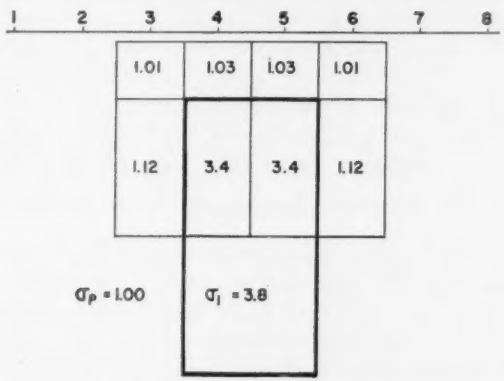


FIG. 5. Result of Analysis of Model Measurements. Model (heavy outline) of conductivity 3.8, can be replaced by eight smaller blocks of indicated conductivities. (After Ness, 1959).

from the ends. The resistivities calculated from the approximation were fitted (least squares) to those measured on the model. The ratio $\sigma_1/\sigma_P$ was 3.8, for which equation (7) gives a contrast factor of 1.7, as compared to the calculated value of 1.6.

## LINEARITY OF THE APPROXIMATION

We were able to put equations (4) and (5) into a form linear in the $\sigma_i$ only because the effect at a boundary was, apparently, proportional to the logarithm of the ratio of the two conductivities separated by that boundary. We found later that the effect is more nearly proportional to an algebraic function of the sums and differences of the two conductivities, so our linearization is not really valid.

We would expect that the approximation would be quite good for small deviations ($\sigma_1 = \sigma_P \pm \epsilon$; $\epsilon \longrightarrow 0$), and that it would deteriorate rapidly as $|\epsilon/\sigma_P|$ increases. Figure 6 shows the result of a model measurement in the worst possible situation:

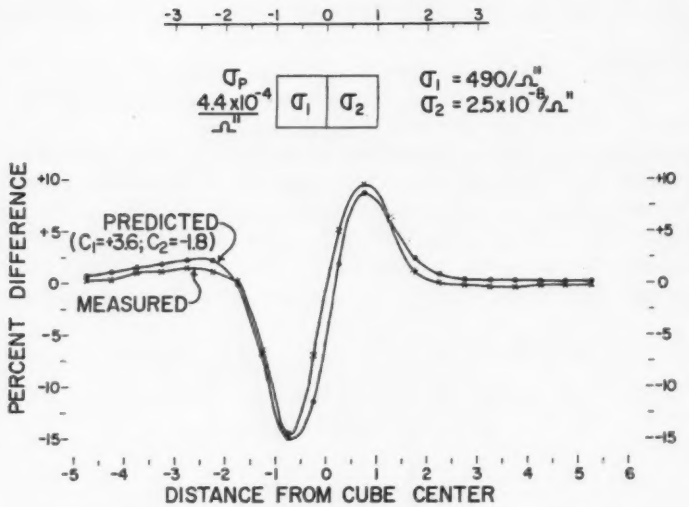


FIG. 6. Telluric Measurement. Percentage difference due to a pair of cubes.

a bakelite cube and a graphite cube in direct contact. From this it is apparent that, due to interaction, the approximation is not as good for a pair of cubes as it is for an isolated cube. It is improbable that the approximation can be, or should be, modified to compensate for this, and we must recognize that the solutions will be semiquantitative at best.

### DIMENSIONAL REQUIREMENTS ON DATA

Regarding the data collection: it is not sufficient that the number of measurements equal the number of unknowns. As was indicated by Stevenson (1934), there must be a certain equivalence between the number of dimensions desired of the solution and the number of dimensions of field measurements taken.[1] That is, for the half-dimensional problem of horizontal layering, $\sigma = \sigma(z)$; $-\infty < z \leq 0$, all we require for interpretation is a half-dimension of information, say an apparent resistivity curve, taken by leaving the source fixed in one location and moving the observation point along a curve away from the source to infinity. Vertical layering is a one-dimensional problem $\sigma = \sigma(y)$; $-\infty < y < \infty$, and we need one full dimension of information for a complete solution, provided only that the

[1] Backus (1960), has proven this principle rigorously for the general three-dimensional problem under the restriction that $\sigma$ has only small deviations from its average over the half space. In his development, Backus uses the concept of a "generalized source," i.e. a voltage applied to the entire surface, whose amplitude varies sinusoidally with $r_1$ and $r_2$. The point source assumed throughout the present work is a special case of this generalized source, derived through a two-dimensional Fourier integral.

observer does not traverse parallel to strike. The case where anomalies are due to horizontal cylinders of various conductivities is a two-dimensional problem, and one way to solve it is to collect apparent resistivity curves for a very large number of source locations on a traverse line perpendicular to strike. This gives us a set of values which can be plotted and contoured like a map, a function of two variables. For the three-dimensional problem which we have been considering, three dimensions of information are necessary. These can be obtained in principle by measuring potentials everywhere on the surface (two dimensions) for sources everywhere along a line (one dimension). In this case there is still one dimension that has not been used—the source is free to move everywhere on the surface, although we have restricted its location to one line. This extra information would be required if the cubes were oriented in some unknown directions other than the $x$, $y$, $z$ axes we used for our measurements. In that case we would need two additional numbers—the direction cosines of the actual cube axes—which could in principle be obtained by shifting the source from its original traverse. The "excess" of information could also be useful in the one-dimensional and two-dimensional problems with transverse anisotropy, provided that the axis of symmetry is horizontal.

## CONCLUSIONS

One should not expect the solutions to be better than semi-quantitative, in view of the approximations involved. With this restriction, the method has been shown to be practical, and to yield satisfactory results.

Several modifications might be tried. One possibility is a method of successive approximations to the potential. This should be tried, keeping in mind that a practical method will be a compromise between economics and quality. A second possible modification would be an alternative method of fitting, although it is not certain whether this is worthwhile with the present approximation. Work is continuing on both possibilities.

Alfano, in a recent paper (1959), presents a rigorous discussion of the problem of an earth made up of horizontal cylinders, and shows that the boundary-value problem is soluable exactly for certain special resistivity distributions. He then attacks the same problem, allowing an arbitrary distribution of cylinder resistivities, and derives a solution which is very similar to that presented here. For geological situations in which there is a distinct strike (that is, where apparent resistivity changes are much more rapid in one direction than in another direction perpendicular to the first), the two dimensional approach is obviously to be preferred, since it requires only the square root of the number of measurements and calculations required in the three-dimensional approach.

The present work started as the author's Ph.D. thesis, submitted to MIT in 1956. It was supervised by Professor T. R. Madden, and was supported by a Morse Committee Fellowship for Computer Applications. Investigation of the problems was continued by Philip Hallof and Norman Ness at MIT, and more

recently by the author at the University of Alberta. Mr. S. A. Bukhari, a graduate student at Alberta, did many of the calculations for checking the model results. The work at Alberta has been supported in part by the Geological Survey of Canada. The writer is grateful for the assistance and support of each of these individuals and groups. He is also indebted to Professor George Backus of MIT for a very original communication on the general problem.

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GEOPHYSICS, VOL. XXV, NO. 6 (DECEMBER, 1960), PP. 1195–1202, 4 FIGS.

# THE REFLECTION OF RAYLEIGH WAVES BY A HIGH IMPEDANCE OBSTACLE ON A HALF-SPACE*

R. W. FREDRICKS† AND L. KNOPOFF†

## ABSTRACT

The reflection of a time-harmonic Rayleigh wave by a high impedance obstacle in shearless contact with an elastic half-space of lower impedance is examined theoretically. The potentials are found by a function—theoretic solution to dual integral equations. From these potentials, a "reflection coefficient" is defined for the surface vertical displacement in the Rayleigh wave. Results show that the reflected wave is $\pi/2$ radians out of phase with the incident wave for arbitrary Poisson's ratio. The modulus of the "reflection coefficient" depends upon Poisson's ratio, and is evaluated as $r_R=0.265$ for $\sigma=0.25$.

## INTRODUCTION

In this paper the reflection of a time-harmonic two-dimensional Rayleigh wave by a high impedance obstacle in shearless contact with a half-space of lower impedance is examined. A theoretical treatment is made, and a "reflection coefficient" calculated. The mathematical boundary value problem is solvable by first expressing it in terms of dual integral equations and then applying the theory of functions to solve these integral equations.

The results show that if the incident Rayleigh wave has a variation $\cos\omega(t-x/\gamma)$ in vertical particle displacement on the surface, then the vertical particle displacement in the reflected wave will be $A \sin\omega(t+x/\gamma)$. This is a phase shift of $\pi/2$ radians with respect to the incident wave.

## BOUNDARY CONDITIONS

Consider the geometry of Figure 1, in which a rigid quarter-space is coupled to an elastic half-space by means of a thin film of inviscid fluid. Let $\boldsymbol{u}(x, y)e^{-i\omega t}$ be the elastic displacement vector, and $\tau_{ij}(x, y)e^{-i\omega t}$ be the components of the stress tensor, where $\boldsymbol{u}(x, y)$ is a solution to

$$\alpha^2\nabla\nabla\cdot\boldsymbol{u} - \beta^2\nabla\times\nabla\times\boldsymbol{u} + \omega^2\boldsymbol{u}(x, y) = 0 \tag{1}$$

and

$$\tau_{ij}/\rho\beta^2 = (\alpha^2/\beta^2 - 2)\delta_{ij}\nabla\cdot\boldsymbol{u} + \partial u_i/\partial x_j + \partial u_j/\partial x_i \tag{2}$$

$$\boldsymbol{u} = (u_x, u_y, 0). \tag{3}$$

Here $\alpha$ and $\beta$ are the $P$ and $S$ wave velocities in the homogeneous, isotropic, perfectly elastic half-space of Figure 1.

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† Institute of Geophysics, University of California, Los Angeles.

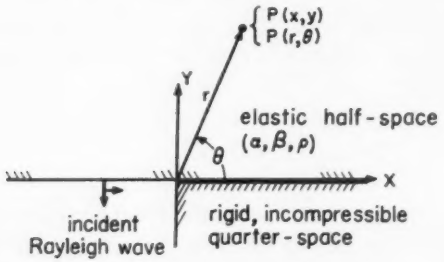


FIG. 1. Schematic diagram of the scattering geometry.

The boundary conditions are accordingly,

$$\begin{aligned} \tau_{yx}(x, 0) &= 0, \qquad -\infty < x < \infty \\ \tau_{yy}(x, 0) &= 0, \qquad -\infty < x < 0 \\ u_y(x, 0) &= 0, \qquad 0 < x < \infty. \end{aligned} \tag{4}$$

## THE INTEGRAL EQUATIONS

If the substitutions

$$u_x = \partial\phi/\partial x + \partial\psi/\partial y, \qquad u_y = \partial\phi/\partial y - \partial\psi/\partial x \tag{5}$$

are introduced into equation (1), then the mathematical problem reduces to that of integrating the two scalar Helmholtz equations

$$(\nabla^2 + k_1^2)\phi(x, y) = 0, \qquad k_1 = \omega/\alpha \tag{6}$$

$$(\nabla^2 + k_2^2)\psi(x, y) = 0, \qquad k_2 = \omega/\beta \tag{7}$$

subject to the conditions of equation (4).

The solutions to (6) and (7) are written in the form

$$\phi(x, y) = \phi_0(x, y) + \frac{1}{2\pi i}\int_L A(k)e^{ikx-\eta_1 y}dk \tag{8}$$

$$\psi(x, y) = \psi_0(x, y) + \frac{1}{2\pi i}\int_L B(k)e^{ikx-\eta_2 y}dk \tag{9}$$

where $L$ is the path shown in Figure 2, and

$$\eta_1 = (k^2 - k_1^2)^{1/2}, \qquad \eta_2 = (k^2 - k_2^2)^{1/2}$$
$$\text{Re}\,(\eta_1, \eta_2) \geq 0. \tag{10}$$

The potential $\phi_0$ and $\psi_0$ specify the incident wave. We choose

$$\phi_0 = C_0 e^{ik_3 x - ay}, \qquad a = (k_3^2 - k_1^2)^{1/2} \tag{11}$$

$$\psi_0 = e^{ik_3 x - by}, \qquad b = (k_3^2 - k_2^2)^{1/2} \tag{12}$$

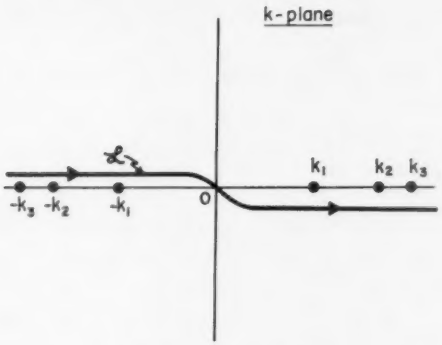


FIG. 2. The path of integration $L$ in the $k$-plane.

where $k_3=\omega/\gamma$ is the positive real root of the Rayleigh equation ($\gamma$ is the Rayleigh wave velocity) for positive $\omega$,

$$R(k) = (2k^2 - k_2^2)^2 - 4k^2\eta_1\eta_2 = 0$$

and the constant $C_0$ is given by

$$C_0 = i\frac{2k_3b}{k_2^2 - 2k_3^2} = i\frac{k_2^2 - 2k_3^2}{2k_3a}.$$

These Rayleigh wave potentials satisfy the conditions of zero normal and shear stress on $y=0$ for all $x$.

By a combination of equations (8)–(12), and (1)–(3), one obtains the set of integral equations,

$$\frac{1}{2\pi i}\int_L \{i2k\eta_1 A(k) + (k_2^2 - 2k^2)B(k)\}e^{ikx}dk = 0, \qquad -\infty < x < \infty, \quad (13)$$

$$\frac{1}{2\pi i}\int_L \{(k_2^2 - 2k^2)A(k) - i2k\eta_2 B(k)\}e^{ikx}dk = 0, \qquad -\infty < x < 0, \quad (14)$$

$$\frac{1}{2\pi i}\int_L \{\eta_1 A(k) + ikB(k)\}e^{ikx}dk = -i\frac{k_2^2}{2k_3}e^{ik_3x}, \qquad 0 < x < \infty. \quad (15)$$

Since $A(k)$ and $B(k)$ are not identically zero on the entire path $L$, then from equation (13) we require that

$$B(k) = i\frac{2k\eta_1}{2k^2 - k_2^2}A(k). \quad (16)$$

The combination of equations (14)–(16) gives the dual integral equations,

$$\frac{1}{2\pi i}\int_L R(k)\,\frac{A(k)}{k_2^2 - 2k^2}\,e^{ikx}dk = 0, \qquad -\infty < x < 0, \tag{17}$$

$$\frac{1}{2\pi i}\int_L \eta_1\frac{A(k)}{k_2^2 - 2k^2}\,e^{ikx}dk + i\,\frac{e^{ik_3x}}{2k_3} = 0, \qquad 0 < x < \infty. \tag{18}$$

## SOLUTIONS TO THE DUAL INTEGRAL EQUATIONS

To solve equations (17) and (18) for $A(k)$, we use the integral representation

$$\frac{1}{2\pi i}\int_L \frac{N_+(k)}{N_+(k_3)}\,\frac{e^{ikx}}{k - k_3}\,dk = e^{ik_3x}, \qquad x > 0, \tag{19}$$

where $N_+(k)$ is any algebraic function having all of its singularities in the lower half-plane Im $(k)<0$ (or on the negative real axis in the degenerate case of no dissipation in the elastic medium). The integral in equation (19) thus supplies an analytic continuation of the left-hand side of equation (18) for negative values of $x$. Combination of equations (18) and (19) leads to

$$\frac{1}{2\pi i}\int_L \left\{\frac{\eta_1}{k_2^2 - 2k^2}\,A(k) + i\,\frac{N_+(k)}{2k_3(k - k_3)N_+(k_3)}\right\}e^{ikx}dk = 0, \tag{20}$$

$$-\infty < x < \infty.$$

Since $A(k)$ and $N_+(k)$ are not zero everywhere on $L$, it follows that

$$A(k) = i\,\frac{(2k^2 - k_2^2)N_+(k)}{2\eta_1 k_3(k - k_3)N_+(k_3)}\,. \tag{21}$$

Let us combine equation (21) with equation (17) to obtain

$$\frac{1}{2\pi i}\int_L i\,\frac{R(k)N_+(k)}{2\eta_1 k_3(k - k_3)N_+(k_3)}\,e^{ikx}dk = 0, \qquad -\infty < x < 0. \tag{22}$$

We define a new function $K(k)$ by

$$K(k) = \frac{2(k_1^2 - k_2^2)(k^2 - k_3^2)}{R(k)}\,. \tag{23}$$

It is clear from (23) and from the definition of $R(k)$ that

$$K(k) \to 1, \qquad |k| \to \infty.$$

It is shown in the Appendix that $K(k)$ can be factored into a product $K_+(k)\cdot K(k)$ where $K_+(k)$ has all of its singularities on the negative real axis, while $K_-(k)$ has all of its singularities on the positive real axis. From the Appendix

$$K_{\pm}(k) = \exp\left\{\frac{1}{\pi}\int_{k_1}^{k_2} \tan^{-1}\left[\frac{4w^2(w^2 - k_1^2)^{1/2}(k_2^2 - w^2)^{1/2}}{(2w^2 - k_2^2)^2}\right]\frac{dw}{w \pm k}\right.$$

If

$$M_{\pm}(k) = \frac{K_{\pm}(k)(k \pm k_1)^{1/2}}{k \pm k_3} \tag{24}$$

it is clear that a general solution to equation (22) is

$$N_{+}(k) = M_{+}(k)P(k),$$

where $P(k)$ is a polynomial in $k$ such that $P(k_3)$ does not vanish.

The polynomial $P(k)$ is fixed by the requirement that the vertical displacement $u_y(x, y)$ be continuous everywhere on $y=0$. The only polynomial which satisfies this continuity condition is a constant. Hence

$$A(k) = i\frac{(2k^2 - k_2^2)K_{+}(k)}{(k_1 + k_3)^{1/2}(k - k_1)^{1/2}(k^2 - k_3^2)K_{+}(k_3)}, \tag{25}$$

$$B(k) = -\frac{2k(k + k_1)^{1/2}K_{+}(k)}{(k_1 + k_3)^{1/2}(k^2 - k_3^2)K_{+}(k_3)}. \tag{26}$$

The appropriate solutions to the differential equations and boundary conditions are

$$\phi(x, y) = \phi_0(x, y) + \frac{1}{2\pi i(k_1 + k_3)^{1/2}K_{+}(k_3)}\int_L \frac{i(2k^2 - k_2^2)K_{+}(k)}{(k - k_1)^{1/2}(k^2 - k_3^2)}e^{ikx - \eta_1 y}dk, \tag{27}$$

$$\psi(x, y) = \psi_0(x, y) - \frac{1}{2\pi i(k_1 + k_3)^{1/2}K_{+}(k_3)}\int_L \frac{2k(k + k_1)^{1/2}}{k^2 - k_3^2}K_{+}(k)e^{ikx - \eta_2 y}dk. \tag{28}$$

## THE REFLECTED RAYLEIGH WAVE

Consider the evaluation of the integrals in equations (27) and (28) when $x<0$. Jordan's lemma is satisfied by the integrands on infinite arcs in Im $(k)<0$. Therefore the integral over the path $L$ can be deformed into the integral around the circle $\Gamma$ drawn about the simple pole at $k=-k_3$, plus the branch line integral $\Gamma_{12}$ taken about the $L$-shaped cuts (Figure 3). By the residue theorem the integrals over $\Gamma$ are readily evaluated and we obtain

$$\phi = \phi_0 + \frac{K_{+}(-k_3)(2k_3^2 - k_2^2)}{2k_3(k_1 + k_3)K_{+}(k_3)}e^{-ik_3x - ay} + (\text{branch line integral over } \Gamma_{12}), \tag{29}$$

$$\psi = \psi_0 + \frac{(k_3 - k_1)^{1/2}K_{+}(-k_3)}{(k_1 + k_3)^{1/2}K_{+}(k_3)}ie^{-ik_3x - by} + (\text{branch line integral over } \Gamma_{12}). \tag{30}$$

The branch line integrals are not written explicitly since we shall not be concerned

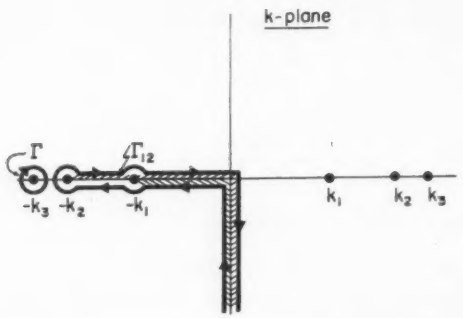


FIG. 3. The deformed path of integration for $x<0$, $\omega>0$.

with them, but shall concentrate on the two integrated terms in equations (29) and (30). It should be remarked, however, that the branch line integrals in equations (29) and (30) represent scattered $P$, $S$, and $P$-$S$ conversion body waves due to the corner at (0, 0). These integrals will be interpreted in a forthcoming treatment of the general diffraction of Rayleigh pulses by structures such as we are considering here.

The vertical component of particle displacement $u_y(x, 0)$ is a quantity readily measured. From equation (5) the part of $u_y(x, 0)$ contributed by the incident at reflected Rayleigh waves alone, say $u_y^{(R)}(x, 0)$ is

$$u_y^{(R)}(x,0) = -(aC_0 + ik_3)e^{ik_3x} - i(aC_0 + ik_3)\left(\frac{k_3 - k_1}{k_3 + k_1}\right)^{1/2} \frac{K_-(k_3)}{K_+(k_3)} e^{-ik_3x}.$$

Let us define a "reflection coefficient" for $u_y^{(R)}(x, 0)$ as the ratio of the coefficient of $e^{-ik_3x}$ that of $e^{ik_3x}$. Then

$$r_R = \left(\frac{k_3 - k_1}{k_3 + k_1}\right)^{1/2} \frac{K_-(k_3)}{K_+(k_3)} e^{i\pi/2} = Ae^{i\pi/2},$$

where $A$ is a real quantity. This solution is the result obtained for $\omega>0$. For $\omega<0$ a similar analysis yields

$$r_R = Ae^{-i\pi/2}.$$

For a Poisson's ratio of $0.25(k_2^2/k_1^2=3)$ we find

$$A = 0.265.$$

Consider the inverse Fourier transform of the quantity

$$\begin{aligned} i \quad & \omega > 0 \\ -i \quad & \omega < 0. \end{aligned}$$

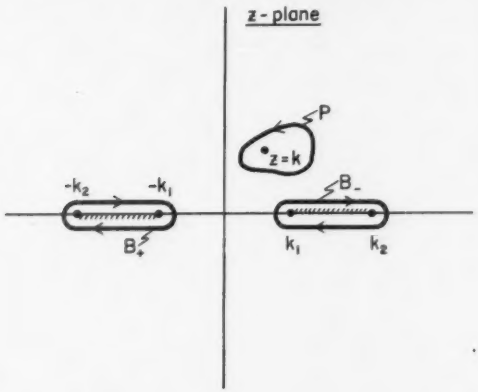


FIG. 4. Paths of integration used in the decomposition of $K(k)$.

This function is $-2/\pi t$ (Erdelyi, et al, 2.2–3). Hence in order to specify the wave shape of the reflected wave, in the case when the incident wave is an impulse, let the time dependence of the incident wave be

$$\delta(t - x/\gamma).$$

Then the reflected wave has a time dependence and amplitude given by

$$-\frac{2}{\pi}\,\frac{a}{t + \dfrac{x}{\gamma}}.$$

An elementary application of the convolution theorem yields the wave shape when the shape of the incident pulse is not that of a delta function.

## APPENDIX

Any function of a complex variable analytic in a horizontal strip can be decomposed into a product of two functions each of which is analytic in an upper and lower half-plane; the region of overlap is the original strip of analyticity. By Cauchy's theorem, we may write

$$\log K(k) = \log K_+(k) + \log K_-(k) = \frac{1}{2\pi i}\int_P \frac{\log K(z)}{z - k}\,dz,$$

where $K(k)$ is the function defined by equation (23), and $P$ is the path of Figure 4. The integral around $P$ is equivalent to an integral taken along the real axis and closed by an arc at infinity in the lower half-plane. This integral has a contribution only from the branch line integral $B_-$. Thus we may write

$$\log K_+(k) = \frac{1}{2\pi i}\int_{B+} \frac{\log K(z)}{z - k}\,dz.$$

A similar construction in the upper half-plane leads to

$$\log K_+(k) = \frac{1}{2\pi i}\int_{B_-} \frac{\log K(z)}{z - k}\, dz,$$

where we use the Principal Branch of the logarithmic function. We obtain, after a calculation involving the definition of $K(z)$,

$$\log K_\pm(k) = \frac{1}{\pi}\int_{k_1}^{k_2} \tan^{-1}\left[\frac{4w^2(w^2 - k_1^2)^{1/2}(k_2^2 - w^2)^{1/2}}{(2w^2 - k_2^2)^2}\right]\frac{dw}{w \pm k}$$

or

$$K_\pm(k) = \exp\left\{\frac{1}{\pi}\int_{k_1}^{k_2} \tan^{-1}\left[\frac{4w^2(w^2 - k_1^2)^{1/2}(k_2^2 - w^2)^{1/2}}{(2w^2 - k_2^2)^2}\right]\frac{dw}{w \pm k}\right.,$$

as the required decomposition.

## REFERENCE

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GEOPHYSICS, VOL. XXV, NO. 6 (DECEMBER, 1960), PP. 1203–1214, 10 FIGS.

# TRANSMISSION AND REFLECTION OF RAYLEIGH WAVES BY WEDGES*

L. KNOPOFF† AND A. F. GANGI‡

## ABSTRACT

Experimental observations have been made of the transmission and reflection of Rayleigh waves by wedges. Results are reported for Rayleigh waves in aluminum wedges. It is observed that the wave shapes of the transmitted and reflected waves differ from that of the incident wave and depend on the angle of the wedge. The change of shape is attributed to an interference between part of the incident wave-form and the radiation from a line source placed at the vertex. A procedure is given for the calculation of the partition between the two terms.

## INTRODUCTION

The problem of the reflection and transmission of Rayleigh waves by wedges is important. It will be shown in a later paper that this process is significant in the production of non-coherent seismic "noise." The problem is difficult to solve mathematically because body $P$ and $S$ waves are also generated by a Rayleigh wave incident on the corner of a wedge. However the problem can be modeled quite simply on seismic laboratory models. In this paper we present results of model experiments and an interpretation of the data.

Consider a homogeneous, isotropic, elastic medium filling the region $0<\theta<\theta_0$, $0<r<\infty$, $-\infty<z<+\infty$ where $(r, \theta, z)$ is a cylindrical coordinate system centered on the corner of the wedge. The remainder is vacuum. The two wedge faces are given by the coordinate planes $\theta=0$ and $\theta=\theta_0$ (Figure 1).

Physically one would expect that a Rayleigh wave incident on a corner would excite the corner as a virtual source. By Huygens' principle, Rayleigh waves should be excited on both faces of the wedge and $P$ and $S$ body waves radiated into the elastic medium. In this paper only the transmitted and reflected Rayleigh waves will be considered.

The simplest theory states that simple reflection and transmission coefficients suffice to describe the Rayleigh waves on the two faces of the wedge. These coefficients are pure numbers, depending only on the angle of the wedge and the properties of the elastic medium. The radiated body waves, of course, have more complicated distribution functions; their amplitudes depend not only on the wedge angle and elastic properties but also upon the angular coordinate $\theta$. A description of reflection and transmission of Rayleigh waves by such a process is given by deBremaecker (1958).

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† Institute of Geophysics, University of California.

‡ Space Electronics Corporation, Glendale, California.

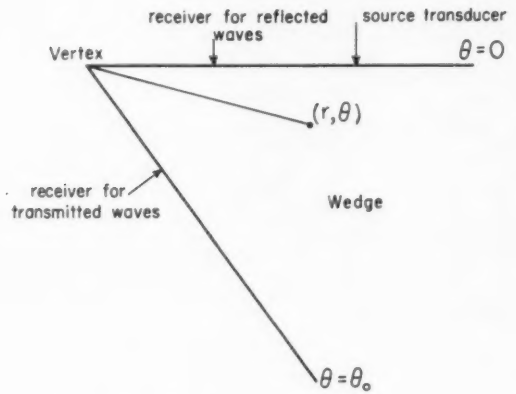



FIG. 1. Schematic diagram of the wedge experiment.

*Experimental measurements*

Measurements of the incident reflected and transmitted Rayleigh waves were made in the laboratory using standard model techniques. Aluminum sheets were cut into wedge shapes (Figure 1). Measurements were taken for wedge angles $\theta_0$ between 45° and 135° in 5° steps and in 10° steps for wedge angles between 230° and 300°.

Motions in thin plates have been found to be a good approximation to two-dimensional elastic wave motions where the "wave lengths" of the pulses are large compared to the thickness of the plates. By the wave length of a pulse we mean the wave length associated with the frequency of the maximum of the Fourier spectrum of that pulse.

A barium titanate source transducer was glued onto the edge of the sheet along one of the wedge surfaces and excited to give a short stress pulse in the plate. The observed incident pulse had three extrema; the time interval between the first and last extrema was about 3.4 μsec. The properties of the aluminum are: plate $P$ wave velocity 5.76 mm/μsec, $S$ wave velocity 3.26 mm/μsec and a plate Poisson's ratio of 0.266. The seismic wave length for $P$ waves is thus about 2 cm.

Rayleigh waves in two-dimensional structures should propagate unattenuated in perfectly elastic materials. Only because of non-elastic effects should there be any attenuation of the surface wave amplitude with distance. The reflected and/or transmitted Rayleigh waves were observed at a number of stations and the attenuation in aluminum was found to be negligible for the accuracy of the experiment. The change in amplitude due to attenuation was less than the scatter due to the irregular placement of the detector and interference from reflected body waves. Measurements were taken at a number of stations for each angle and

the results averaged to avoid experimental inaccuracies resulting from detector placement error.

Typical observations of the normal component of motion of Rayleigh waves on aluminum plates cut in wedge shapes are shown in Figure 2. The details of the measurements are given later. Comparison of the reflected and transmitted Rayleigh waves with the incident Rayleigh wave shows that there is a change in the wave-form of these waves. This is especially clear in the case of the transmitted wave for the 80° wedge. It is apparent that a more complicated interpretation of the data is necessary than that offered above; the simple theory is not sufficient to fit the observations.

*Interpretation*

The basis for the interpretation comes by noting that, in the case of the incidence of a simple pulse upon the degenerate wedge $\theta_0 = 2\pi$, i.e. a half-plane discontinuity, the scattered wave does not have the same time dependence. In particular let an incident plane pulse be represented by $K\delta(t-x/c)$ where $K$ is some amplitude and $\delta(t-x/c)$ is the delta function. Then the wave scattered by a two-dimensional half-plane has the form $K'(t-r/c)^{-1/2}H(t-r/c)$ where $H(t-r/c)$ is the unit step function, $r$ is the distance from the edge of the discontinuity and $K'$ is a function of the angle (deHoop, 1958). This description is satisfactory as long as we consider motions close to the onset time $r/c$. In other words, the edge of the discontinuity acts as a two-dimensional line source in an infinite medium.

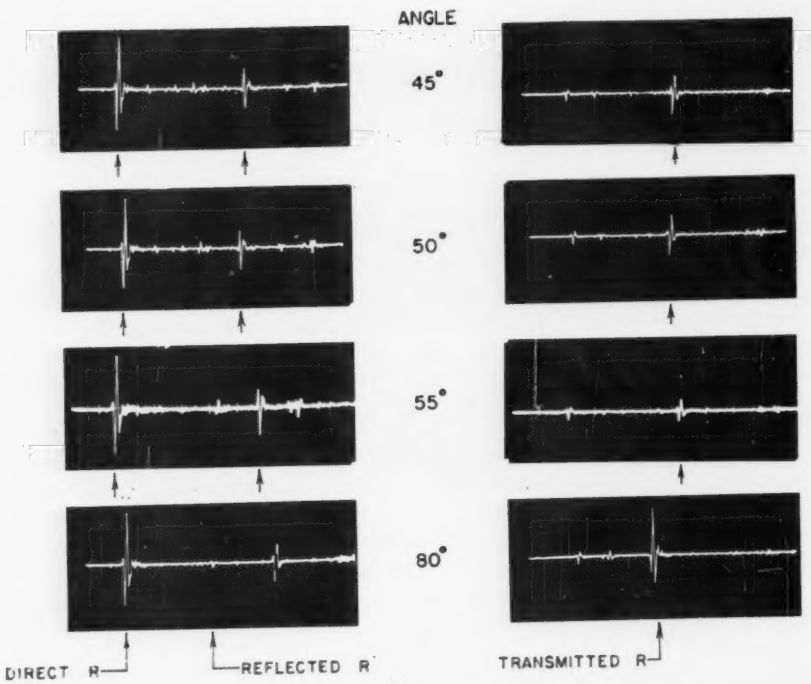
On the other hand, for the degenerate wedge having wedge angle $\pi$, the transmission coefficient for Rayleigh waves is unity and the reflection coefficient is zero. In more mathematical terms, for an incident Rayleigh pulse $\delta(t-x/c)$ the transmitted Rayleigh pulse is also $\delta(t-x/c)$.

Hence, we represent the transmission and reflection of Rayleigh waves as the sum of two terms. The first of these corresponds to the normal transmission and reflection with unchanged wave-forms. The second corresponds to the Rayleigh waves radiated from a line source placed at the vertex of the wedge. It can be shown that, if the line source is excited as a delta function, the Rayleigh waves from this line source behave as $A(ct/x-1)^{-1/2}H(ct/x-1)$ at a great distance from the vertex where $x$ is a coordinate along the surface. The amplitude $A$ is an unknown function of the wedge angle. The wave shape from the line source is assumed to be independent of the wedge angle.

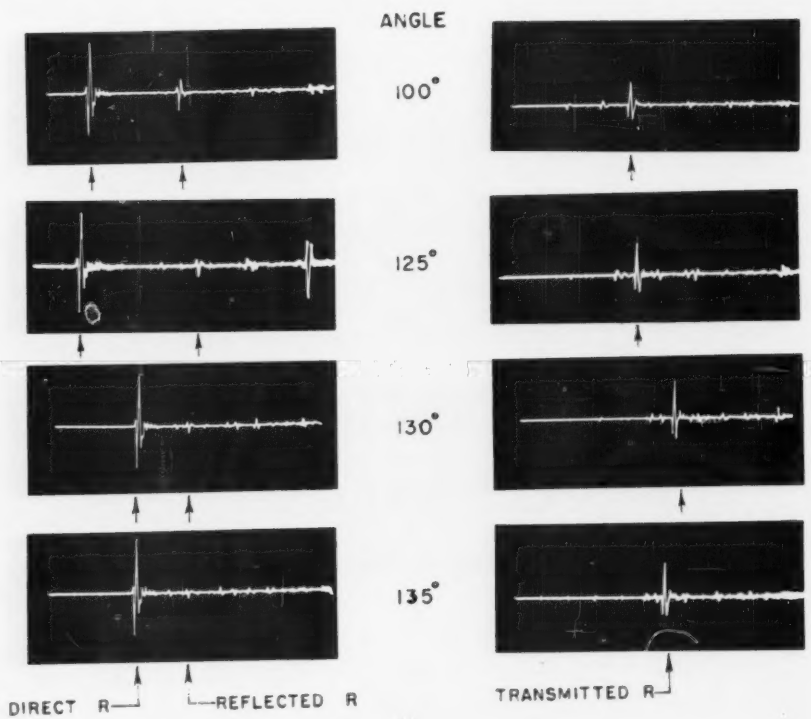
The Fourier transform of the radiation from a line source at the vertex of a wedge is

$$\int_0^\infty a(n,\theta_0)H_n^{(1)}\left(\frac{\omega}{v_p}r\right)e^{in\theta}dn + \int_0^\infty b(n,\theta_0)H_n^{(1)}\left(\frac{\omega}{v_s}r\right)e^{in\theta}dn,$$

where $a$ and $b$ are determined from the boundary conditions on the faces of the


ANGLE
45°
50°
55°
80°
DIRECT R
REFLECTED R
TRANSMITTED R

(a)


ANGLE
100°
125°
130°
135°
DIRECT R
REFLECTED R
TRANSMITTED R

(b)

wedge and $v_p$ and $v_s$ are the $P$ and $S$ wave velocities. Passing to the limit of large argument $\omega r/v \gg 1$ by the use of the asymptotic expansions for the Hankel functions, the inverse transforms of the integrals that result have a behavior of the type

$$\frac{C(\theta, \theta_0)}{r^{1/2}} (vt/r - 1)^{-1/2} H(vt/r - 1)$$

for times near the arrival time $r/v$.

Thus, the virtual source represented by the corner performs two operations for an incident surface wave having a delta function time dependence. These are a reproduction and a mild integration, the latter corresponding to the term $(V_R t/x - 1)^{-1/2} H(V_R t/x - 1)$ where $V_R$ is the velocity of Rayleigh waves. We represent the reflected and transmitted waves as the sum

$$A_{R,T}(\theta_0, \sigma)\delta(v_R t/r - 1) + B_{R,T}(\theta_0, \sigma)(V_R t/r - 1)^{-1/2} H(V_R t/r - 1) \qquad (1)$$

for times close to the onset time for an incident delta function. The subscripts $R$ and $T$ refer to the reflected and transmitted Rayleigh waves. The functions $A$ and $B$ are dimensionless coefficients indicating the partition between the two processes and $\sigma$ is Poisson's ratio.

The use of expressions of the type (1) are valid for times close to the arrivals. The errors are not significant if the actual wave-forms of the input pulses are of short duration compared with the travel times (Knopoff, 1958).

The experimental input pulse is not a delta function but instead has a finite duration. We approximate the input wave function as the sum of three gaussian functions (Figure 3). This is not an inaccurate decomposition. We now find the response to the system to excitation by a single gaussian function. If the input wave function is $\exp\{-\beta^2(V_R t/r - 1)^2\}$ then, by the convolution theorem, the received motion for both reflected and transmitted waves will be

$$f_{R,T}(V_R t/r, \theta_0, \sigma)$$

$$= A_{R,T}(\theta_0, \sigma) e^{-\beta^2(V_R t/r - 1)^2} + B_{R,T}(\theta_0, \sigma) \int_0^\infty u^{-1/2} e^{-\beta^2(V_R t/r - 1 - u)^2} du. \qquad (2)$$

Let $\tau$ be the dimensionless arrival time of Rayleigh waves

$$\tau = \beta(V_R t/r - 1).$$

FIG. 2 (a & b). Typical observations of the incident reflected and transmitted Rayleigh waves for wedges of different angles.

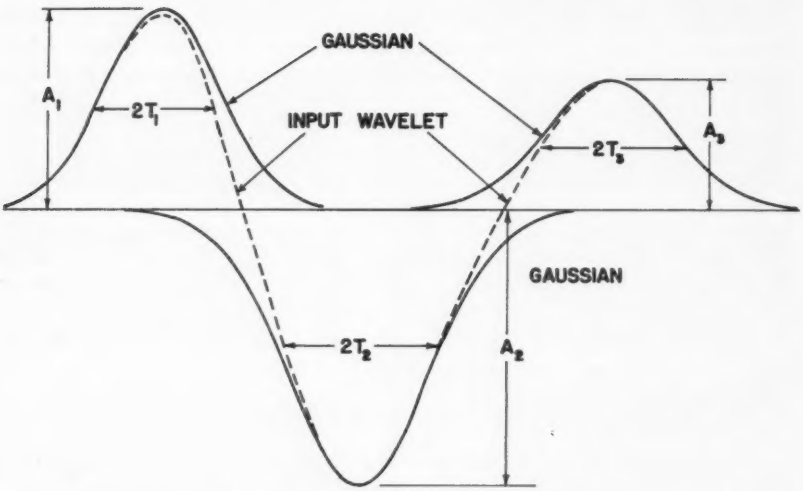



FIG. 3. Representation of the wavelet of the incident wave as the sum of three gaussian functions.

The wave function at the receiver is thus,

$$f_{R,T}(\tau, \theta_0, \sigma) = A_{R,T}e^{-\tau^2} + B_{R,T}\beta^{-1/2}\int_0^\infty e^{-(\tau-w)^2}w^{-1/2}dw, \tag{3}$$

$$= A_{R,T}f_0(\tau) + B_{R,T}\beta^{-1/2}f_{-1/2}(\tau), \tag{4}$$

where $f_0$ and $f_{-1/2}$ are defined as the gaussian function and the convolution integral respectively.

The universal function $f_{-1/2}$ has been evaluated numerically on SWAC[1] for the range $\tau$: $-3(.1)3$ (Table I). Outside this range for large positive or negative $\tau$ standard approximations apply. For instance for large positive $\tau$.

$$f_{-1/2}(\tau) \approx (\pi/\tau)^{1/2}, \qquad \tau \gg 1.$$

This result can be applied to any gaussian function of arbitrary width by suitably selecting the scale factor $\beta$. Thus, for the given input function (Figure 3) the convolution with $((V_R t/r)^2-1)^{1/2}$ is given in Figure 4. The solid curves are the convolutions of the individual gaussian functions and the dotted curve is the sum of these three contributions suitably spaced in time.

For the particular input wave function $g_0(t)$ given in Figure 3 the reflected and transmitted wavelets will be the functions.

$$f_{R,T}\{t, \theta_0, \sigma\} = A_{R,T}(\theta_0, \sigma)[g_0(t) + \alpha_{R,T}(\theta_0, \sigma)g_{-1/2}(t)], \tag{5}$$

[1] Standards Western Automatic Computer, an electronic digital computer at University of California, Los Angeles.

TABLE I

$$f(t) = \frac{1}{2}\int_0^\infty \frac{1}{u^{1/2}}\, e^{-(t-u)^2} du$$

| $t$ | $f(t)$ | $t$ | $f(t)$ | $t$ | $f(t)$ |
|---|---|---|---|---|---|
| −3.0 | .00000 | −1.0 | .2067 | 1.0 | .9868 |
| −2.9 | .0001 | −0.9 | .2587 | 1.1 | .9526 |
| −2.8 | .0002 | −0.8 | .3181 | 1.2 | .9166 |
| −2.7 | .0003 | −0.7 | .3844 | 1.3 | .8803 |
| −2.6 | .0005 | −0.6 | .4564 | 1.4 | .8444 |
| −2.5 | .0008 | −0.5 | .5328 | 1.5 | .8100 |
| −2.4 | .0013 | −0.4 | .6116 | 1.6 | .7775 |
| −2.3 | .0021 | −0.3 | .6906 | 1.7 | .7472 |
| −2.2 | .0033 | −0.2 | .7674 | 1.8 | .7193 |
| −2.1 | .0052 | −0.1 | .8396 | 1.9 | .6938 |
| −2.0 | .0080 | 0.0 | .9049 | 2.0 | .6706 |
| −1.9 | .0120 | 0.1 | .9630 | 2.1 | .6495 |
| −1.8 | .0177 | 0.2 | 1.0089 | 2.2 | .6304 |
| −1.7 | .0257 | 0.3 | 1.0432 | 2.3 | .6129 |
| −1.6 | .0367 | 0.4 | 1.0655 | 2.4 | .5970 |
| −1.5 | .0512 | 0.5 | 1.0758 | 2.5 | .5824 |
| −1.4 | .0702 | 0.6 | 1.0749 | 2.6 | .5690 |
| −1.3 | .0946 | 0.7 | 1.0640 | 2.7 | .5566 |
| −1.2 | .1225 | 0.8 | 1.0446 | 2.8 | .5450 |
| −1.1 | .1622 | 0.9 | 1.0185 | 2.9 | .5343 |

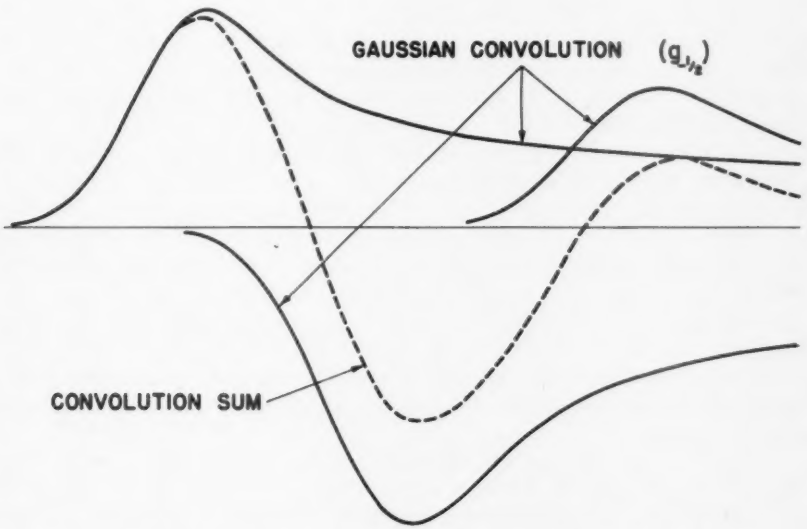



FIG. 4. Convolution of each of the three gaussian functions with $(ct/x-1)^{-1/2}$ and the convolution of the incident wavelet.

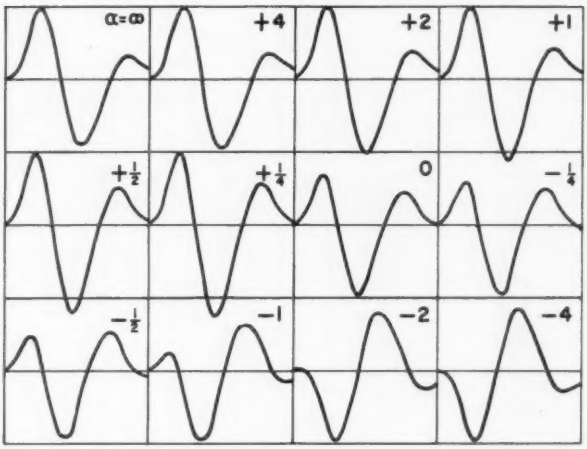



FIG. 5. The sum $g_0(t)+\alpha g_{-1/2}(t)$ with $\alpha$ as a parameter.

where $g_{-1/2}$ is the function of Figure 4. We have written $\alpha_{R,T}=B_{R,T}/A_{R,T}$ and the time scale is measured such that $\beta=1$. The function $f/A$ has been calculated for values of $\alpha=\infty\,(A=0)$, $\pm 4$, $\pm 2$, $\pm 1$, $\pm\frac{1}{2}$, $\pm\frac{1}{4}$, 0. These are shown in Figure 5 and represent possible output wavelets for the appropriate ratio coefficient $\alpha$. It can be seen that the shape of the pulse changes with $\alpha$. We note the appearance of an additional loop on the right for $\alpha<0$ and note the disappearance of the loop on the left for $\alpha<-2$.

Identifying the first negative loop as having amplitude $a_2$ and numbering the loops from 1 to 4, the ratios of the amplitudes $a_1/a_2$, $a_3/a_2$ and $a_4/a_2$ may be plotted as a function of $\alpha$ (Figure 6). This curve is now the basis of the interpretation.

The procedure for the calculation of $\alpha$ from the data is as follows. Number the loops, measure the amplitudes, take the ratios and enter in Figure 6. The ratios should all yield an identical value of $\alpha$. There is some ambiguity in determining the first negative loop as the multiplier function $A_{R,T}$ may be negative. However, any error in number will show up in terms of ratios of amplitudes that do not yield a consistent value of $\alpha$; the two (or three) values of $\alpha$ corresponding to the amplitude ratios must all have the same numerical value for a given reflection or transmission.

Once the values of $\alpha_{R,T}$ are known, the calculation of the quantities $A_R$, $B_R$, $A_T$ and $B_T$ is elementary. Auxiliary curves of the amplitudes $a_i$ as functions of $\alpha$ are useful in this last interpretation (Figure 7) where the curves have been normalized to the values in the incident pulse, $\alpha=0$.[2] It should be emphasized that

[2] By comparing the values of $a_i$ for the value of $\alpha$ already obtained with the measured values of $a_i$, $A$ can be determined. The value of $B$ is obtained from the definition of $\alpha$.

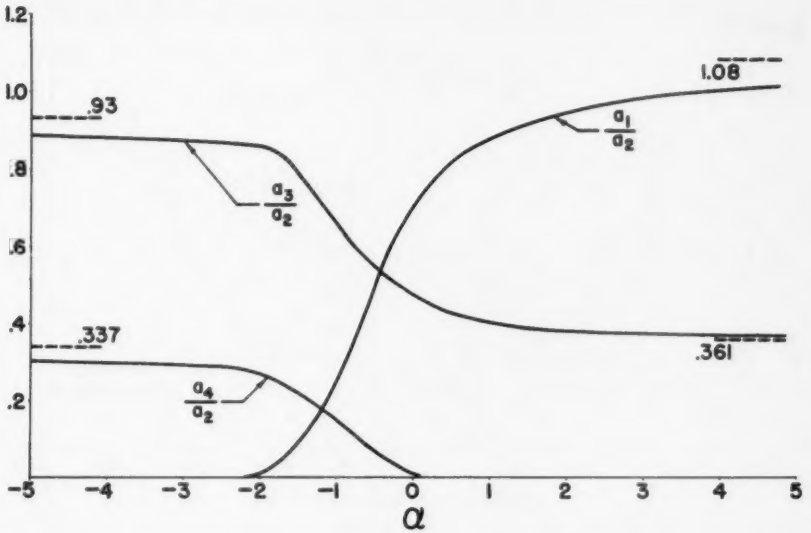



FIG. 6. Relative amplitudes of the loops in the received wavelet as a function of the parameter $\alpha$.

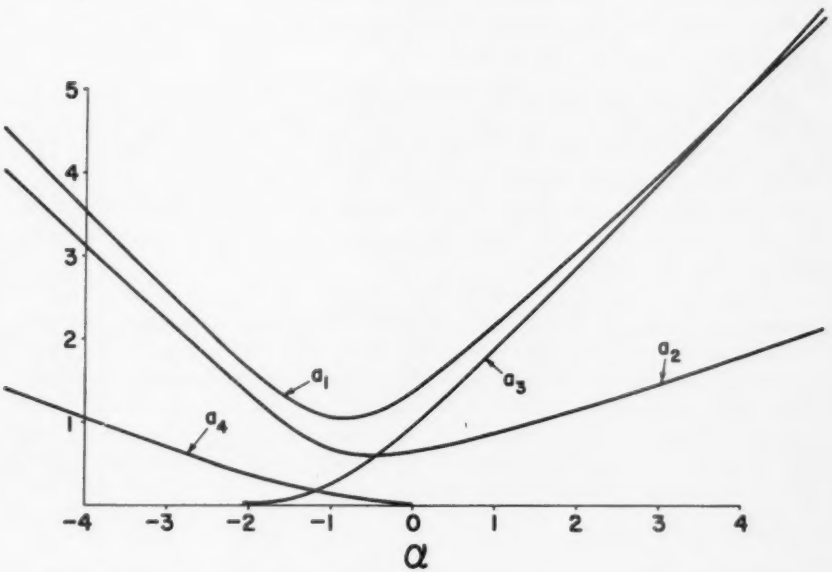



FIG. 7. Amplitudes of the loops in the received wavelet as a function of the parameter $\alpha$.

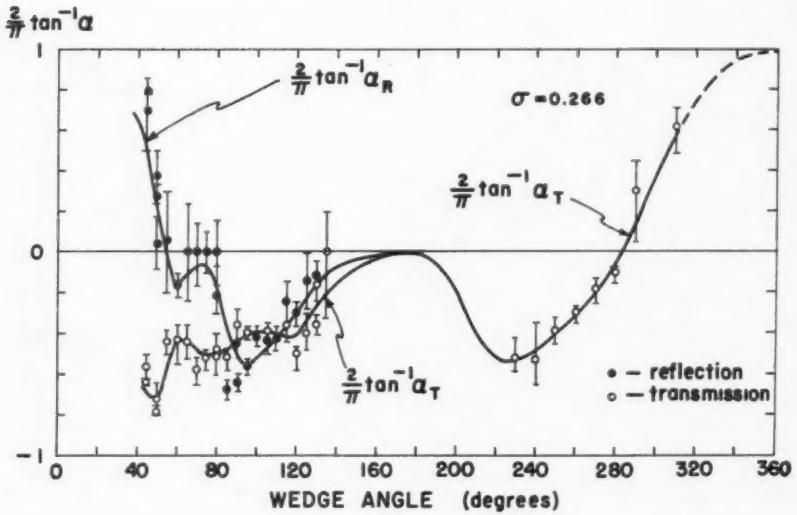



FIG. 8. Experimental values for $\alpha(\theta_0)$.

the values of $\alpha_R$, $\alpha_T$, $A_R$, $A_T$, $B_R$ and $B_T$ thus calculated hold for any shape of pulse as long as the pulse duration is short compared with the travel time.

*Reflection and transmission coefficients*

By the method described in the preceding section the results for $\alpha_{R,T}(\theta_0, 0.266)$ are presented in Figure 8. The curves of $a_n/a_2$ are very flat for large positive or negative $\alpha$ and the wave-form does not change much with large changes of $\alpha$ in this region, hence an inaccuracy in $\alpha$ may be reported that may be large but yet is of little significance. In order to avoid this complication we have compressed the scale $-\infty < \alpha < \infty$ to $-1 < 2/\pi \tan^{-1}\alpha < 1$ and plotted the function $2/\pi \tan^{-1} \alpha_{R,T}(\theta_0, 0.266)$.

The results in Figure 8 together with the values of the reflection and transmission coefficients $A_R$, $B_R$, $A_T$, $B_T$ (Figure 9) form the complete interpretation.

It should be noted that the interpretation curves for Figures 6 and 7 are not universal. They depend severely upon the shape of the input pulse (Figure 3). This condition requires that the input pulse be kept constant for the use of the interpretation curves. Mild variation in the experimental input wave-form was the major source of the inaccuracy in the interpretation. Interpretation curves must be recomputed for each input function.

*Energies*

deBremaecker (1958) has reported results of reflection and transmission of Rayleigh waves at corners for incident Rayleigh waves. The analysis therein pre-

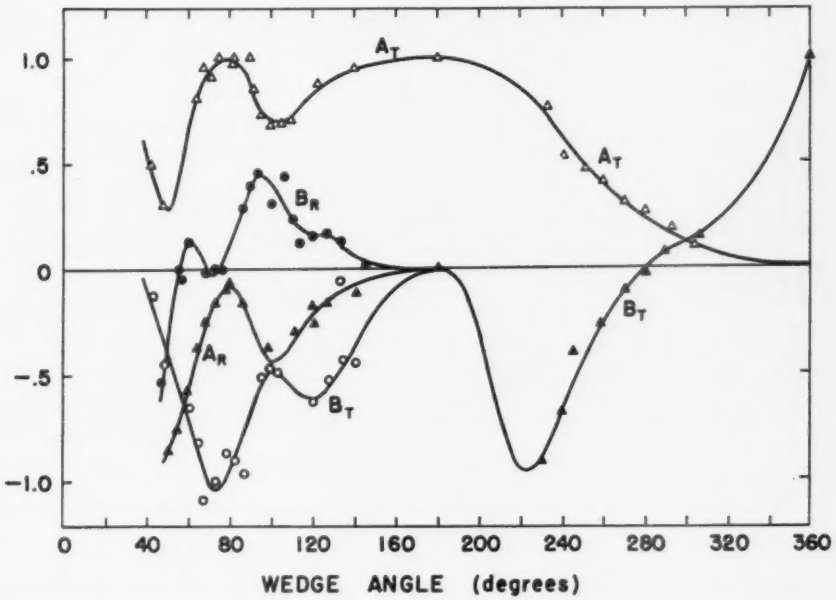



FIG. 9. Experimental values for $A_R$, $B_R$, $A_T$, $B_T$.

sented takes no account of the changes of wave shape upon reflection. The quality of the seismic pulse in the experiments is poor. Comparison with deBremaecker's work may be made for the energy reflection and transmission coefficients.

Consider a gaussian wavelet $A_0 \exp -(t/t_0)^2$ where $t_0$ is the breadth of the wavelet and $A_0$ is the peak amplitude of the wavelet. The energy in the wavelet is

$$\int_{-\infty}^{\infty} A_0^2 \exp(-2t^2/t_0^2)dt = A_0^2(\pi/2)^{1/2}t_0. \tag{6}$$

We thus compute the energy in a wavelet with $N$ loops as

$$\sum_{i=1}^{N} A_i^2 \Delta t_i, \tag{7}$$

where $A_i$ is the amplitude of the peak of the $i$th loop and $\Delta t_i$ is the width of the loop, taken here to be the time interval between zeros of the $i$th loop. This may be normalized to the input wavelet. The energy in (7) is an approximation neglecting the "overlap" or interaction of the individual gaussian functions.

Energy reflection and transmission coefficients for the wedges are presented in Figure 10 and compared with deBremaecker's results. We note that although

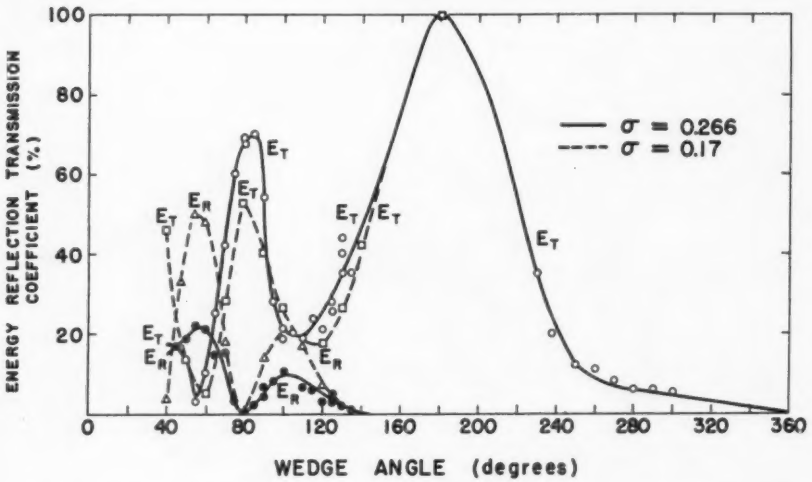



FIG. 10. Energy reflection and transmission coefficients. Results for aluminum ($\sigma=0.266$) are compared with those obtained by deBremaecker ($\sigma=0.17$).

the present data have been taken at an angle interval of 5°, no significant differences are observed in the structure of the curves obtained by deBremaecker for an angle interval of 10°. Significant shifts in the peaks both in angle and in magnitude, are observed. We note that the Poisson's ratios for the two experiments are different.

The reflected energy for wedge angles greater than 180° is less than 1 percent of the incident energy.

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GEOPHYSICS, VOL. XXV, NO. 6 (DECEMBER, 1960), PP. 1215–1228, 5 FIGS.

# ON A SUCCESSIVE APPROXIMATION METHOD FOR INTERPRETING GRAVITY ANOMALIES*

Z. FRANKENBERGER DANES†

## ABSTRACT

A new method for quantitative interpretation of gravity anomalies is presented. The disturbing body is represented by a finite number of vertical prisms arranged on a pre-determined, regular grid. The horizontal dimensions of the individual prisms are small enough that they can be approximated by vertical-line mass elements at the axis of the prisms. Formulas for gravity due to one prism are derived and, for the case of Gulf Coast salt densities, plotted on Figure 1. Gravity due to the whole body is an algebraic sum of the contributions of all prisms at the appropriate depths and distances.

This method makes possible the direct interpretation by successive approximations by introducing proper geologic limitations. All the numerical work can be conveniently done on a high-speed digital computer. The method is especially suitable for features with predominant vertical dimension such as salt domes and igneous plugs. It gives at least the same, and possibly higher, degree of accuracy as the graphical dot chart methods and, carried out on a digital computer, should be about two thousand times faster.

## SYMBOLS USED

$a$ = theoretical logarithmic density contrast of salt against sediments at the depth of one ft in the Gulf Coast

$b$ = theoretical increase in logarithmic density of the Gulf Coast sediments between 1-ft and 10-ft depths

$d$ = distance of axes of two adjacent prisms; spacing unit

$g$ = observed gravity anomaly due to the mass $M$

$\bar{g}$ = gravity of a vertical line element

$m$ = mass at the point $(x, y, z)$

$n$ = number of successive approximations

$r = \sqrt{(x-x_0)^2+(y-y_0)^2+z^2}$

$x$ = horizontal coordinate, East, in feet

$y$ = horizontal coordinate, North, in feet

$z$ = depth, in feet

$z_B$ = depth to bottom of prism

$z_T$ = depth to top of prism

$A$ = cluster of prisms approximating the disturbing mass $M$

$F = F(x, y, z) = 0$ = formula of the surface of the anomalous mass $M$

$G = \lim_{z \to \infty} \left( \frac{\sigma}{r} - \int \frac{d\sigma}{r} \right)$ See equation 6

$H$ = half width of observed anomaly

$\overline{H}$ = half width of anomaly of a line element

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† Boeing Airplane Co., Seattle, Washington.

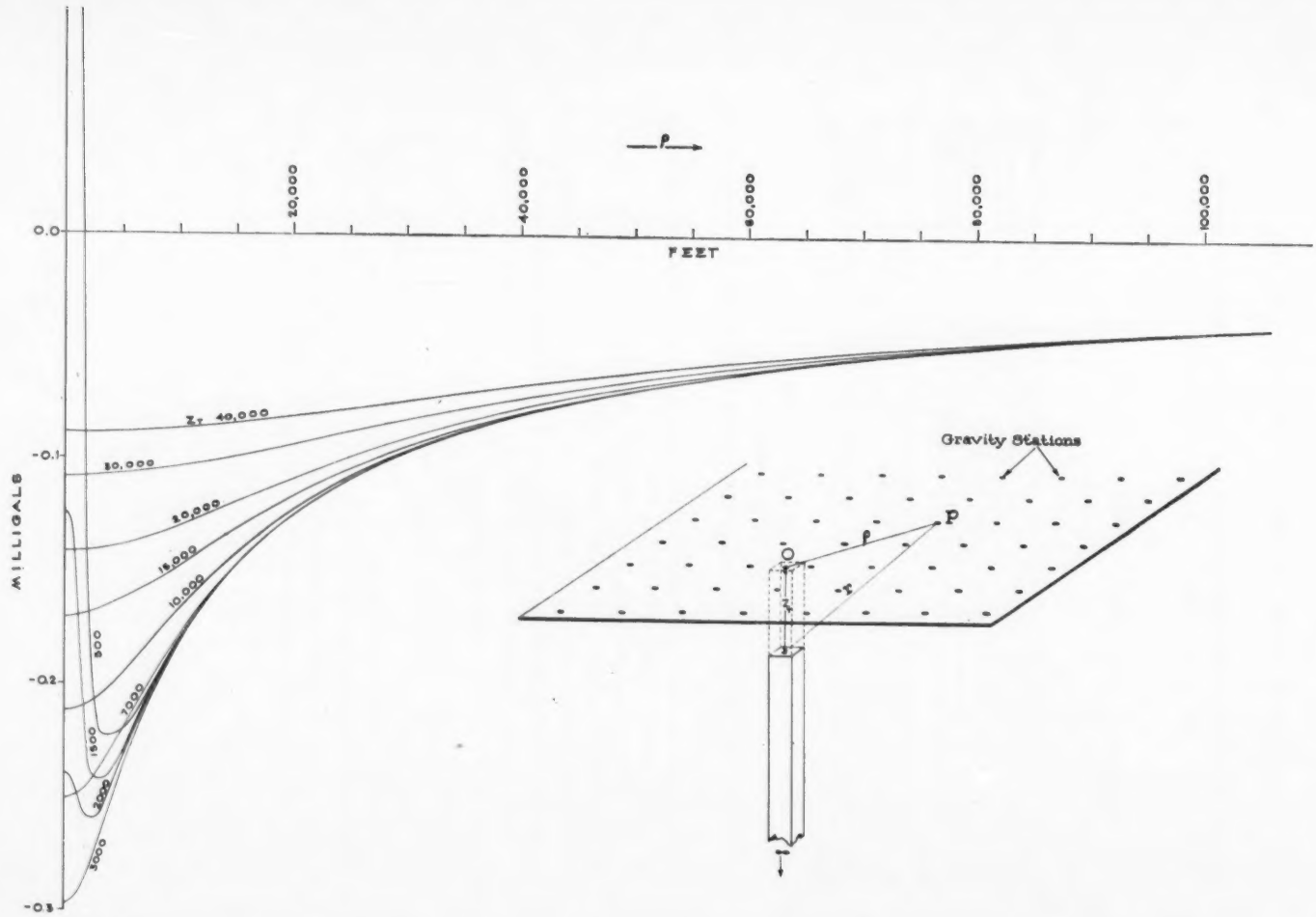



FIG. 1. Gravity effects of an elementary semi-infinite vertical salt prism depth to top $z_T$ as parameter density contrast $\Delta\sigma = 1.023 - 0.2897 \log_{10} Z$ horizontal cross-section of each prism = 2,000 by 2,000 sq. ft.

$L$ = vertical line element
$M$ = anomalous subsurface mass
$N$ = number of prisms approximating $M$
$P$ = reference point, gravity station
$R$ = residual gravity map; radius of cylindrical shell
$S$ = horizontal cross sectional area of an elementary prism
$V$ = volume of the anomalous mass $M$
$\gamma$ = gravity constant = $\frac{2}{3}10^{-7}$ c.g.s.u.
$\delta = \bar{g} - g$ = difference between gravity of $M$ approximated by line elements and actual gravity
$\epsilon$ = the ratio between the tolerable discrepancy and the total gravity anomaly

$$\xi = \frac{1}{8} \cdot \frac{d^2}{z^2 + 9/8d^2}; \qquad \text{See equation 20}$$

$\rho = \sqrt{(x-x_0)^2 + (y-y_0)^2}$
$\rho_0$ = distance at which $\delta = 0$
$\sigma$ = density contrast a point $(x, y, z)$
$\pi$ = closed surface around $M$

## INTRODUCTION

A mass anomaly $M$ causes at a point $P$ an anomaly $g$ in the vertical component of the earth's gravitational field:

$$g = \int_M \frac{\gamma z dm}{r^3} = \gamma \int_V \frac{z\sigma dV}{r^3}$$

$$= \gamma \int_{z_1}^{z_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} \frac{\sigma z dx dy dz}{[(x - x_0)^2 + (y - y_0)^2 + z^2]^{3/2}}. \tag{1}$$

The constriction on the limits is given by

$$F(x, y, z) = 0. \tag{2}$$

To perform the integration in equation (1) is a difficult, and often impossible, task even for simple $F$ and $\sigma$. Therefore, graphical, numerical, and analog methods have been developed. The first and second methods give satisfactory results but are too time consuming. Analog methods are fast, but the accuracy is limited.

With the development of fast digital computers, numerical methods become practicable and may even replace the trial-and-error way to define $F$.

To present one way to the solution of this problem is the purpose of this paper.

## THEORY

The vertical component of gravity, $dg$, at a point, $P_{(x_0, y_0, 0)}$ due to a mass

element $dm$, is

$$dg = \gamma \frac{z dm}{r^3} = \frac{\gamma \sigma z dV}{r^3}.$$

Integrating over the whole mass $M$ gives equation (1) where the limits satisfy equation (2).

If the density contrast is a function of depth only,

$$\sigma = \sigma(z), \tag{3}$$

and if the horizontal dimensions are constant and negligible compared to the distance from $P$, approximately

$$\bar{g} = \gamma S \int_{z_1}^{z_2} \frac{\sigma z}{r^3}\, dz. \tag{4}$$

Integrating by parts,

$$\bar{g} = \gamma S \left( \frac{\sigma}{r} \Big|_{z_1}^{z_2} - \int_{z_1}^{z_2} \frac{d\sigma}{r} \right). \tag{5}$$

In all practical cases, $\sigma$ can be approximated by a function of $z$ which permits integration. However, it is an advantage to use such a function for which the limit

$$G = \lim_{z \to \infty} \left( \frac{\sigma}{r} - \int \frac{d\sigma}{r} \right) \tag{6}$$

exists. Then all prisms can be assumed to extend downward to infinity and graphs or tabulations can be made for $z_T$ only; and, from (5) and (6)

$$\bar{g} = \gamma S \left[ \left( \frac{\sigma}{r} - \int \frac{d\sigma}{r} \right)_{z=z_T} - G \right]. \tag{7}$$

Gravity of a finite prism is then obtained as a difference of gravity of two semi-infinite prisms with the depths at the top and bottom of the finite prism, respectively.

In the Gulf Coast, where the density contrast of the salt of the domes against the surrounding sediments is given (approximately) by the formula

$$\sigma = a + b \log_{10} z, \tag{8}$$

formula (7) gives

$$\bar{g} = a \frac{\gamma d^2}{\sqrt{(x-x_0)^2 + (y-y_0)^2 + z_T^2}} + b\gamma d^2 \left[ \frac{\log_{10} z_T}{\sqrt{(x-x_0)^2 + (y-y_0)^2 + z_T^2}} + \frac{\log_{10} z_T - \log_{10} \left( \sqrt{(x-x_0)^2 + (y-y_0)^2} + \sqrt{(x-x_0)^2 + (y-y_0)^2 + z_T^2} \right)}{\sqrt{(x-x_0)^2 + (y-y_0)^2}} \right]. \tag{9}$$

This formula (9) is plotted on Figure 1 for $a=1.023$, $b=-0.2897$, $d=2{,}000$ ft, and $z_T=500$ ft; 1,500 ft; 2,000 ft; 3,000 ft; 7,000 ft; 10,000 ft; 15,000 ft; 20,000 ft; 30,000 ft; and 40,000 ft respectively.

An obvious advantage of the logarithmic formula (8) is in the possibility of subsequent density adjustments. Both parameters $a$ and $b$ appear as multiplicative factors, so that if each bracket is evaluated separately, density adjustments involve only multiplications and additions of two terms for each station.

Next let us check how closely $g$ is approximated by $\bar{g}$. To that end, let us follow the subsequent reasoning.

First, let us assume that $N=1$ and $M>0$. (For negative density contrasts, such as those of deep salt domes, where $M<0$, the changes are obvious.)
From Gauss' Theorem it follows that

$$\oiint_{\Pi} g d\Pi = 4\pi\gamma M. \tag{10}$$

But also

$$\oiint_{\Pi} \bar{g} d\Pi = 4\pi\gamma M, \tag{11}$$

so that

$$\oiint_{\Pi} (\bar{g} - g) d\Pi = \oiint_{\Pi} \delta d\Pi = 0. \tag{12}$$

For a point at the axis only, all $d\bar{g}$'s are added algebraically, whereas $dg$'s are added vectorially; therefore $\delta$, must reach its maximum value, $\delta_{\max}$, at the axis. If $\delta_{\max}$ does not exceed the limits of tolerable errors, other $\delta$'s, smaller than $\delta_{\max}$, certainly do not either. Let us then carry out our proof for $\delta_{\max}$.

Somewhere off the axis, at the distance $\rho_0$, $\delta=0$ and beyond that $\delta<0$, reaching a minimum. If $\pi$ extends to infinity, $\delta$ converges to zero asymptotically.

Let us first assume a semi-infinite cylindrical shell of radius $R$ and constant density contrast. For a point at its axis, equation (1) yields

$$g = \gamma \int_{z_T}^{\infty} \int_{\alpha=0}^{2\pi} \frac{\sigma z R d\alpha dz}{(z^2 + R^2)^{3/2}} = \frac{2\pi\gamma\sigma R}{(z_T^2 + R^2)^{1/2}}. \tag{13}$$

From equation (5),

$$\bar{g} = \frac{2\pi\gamma\sigma R}{z_T}, \tag{14}$$

thus

$$\delta = \bar{g} - g = \frac{2\pi\gamma\sigma R}{z_T}\left\{1 - \frac{1}{\sqrt{1 + \dfrac{R^2}{z_T^2}}}\right\}. \tag{15}$$

Postulating that

$$\delta_{\max} \leq \epsilon \bar{g}$$

gives approximately, for sufficiently small $\epsilon$,

$$R \leq z_T \sqrt{2\epsilon} \tag{16}$$

as the upper limit of $R$. The condition is certainly satisfied by another body with the same vertical axis and entirely within $R$. If, therefore, the diagonal of a square prism is equal to $2R$,

$$\tfrac{1}{2} d\sqrt{2} \leq z_T \sqrt{2\epsilon}$$

and

$$\epsilon \geq \frac{1}{4} \left( \frac{d}{z_T} \right)^2 . \tag{17}$$

Table I shows the maximum possible errors introduced by this method.

TABLE I

MAXIMUM POSSIBLE ERROR AS A FUNCTION OF RATIO $z_T/d$

| $z_T/d$ | $\epsilon\%$ |
|---|---|
| 2 | 6.2 |
| 3 | 2.8 |
| 4 | 1.6 |
| 5 | 1.0 |
| 10 | 0.2 |

(Actually, the situation is much more favorable. In the example on Figure 5, very satisfactory results are obtained with $z_T = d$).

It remains to show that $\rho_0$ is actually less than the prism spacing , so that the discrepancies of the adjacent prisms do tend to cancel one another. To show that, let us consider a square prism of cross-sectional area $S = d^2$. If approximated by a vertical line element at its axis, the gravity of this prism at point $P$ at the axis of the adjacent prism (at distance $d$) is

$$\bar{g} = \gamma d^2 \sigma \frac{1}{\sqrt{z^2 + d^2}} . \tag{18}$$

Now let us divide the same prism into four equal prisms of $S' = \tfrac{1}{4} d^2$ (Figure 4), replace each of them by a vertical line element at its particular axis, and calculate their combined effect at $P$:

$$\bar{g}' = \frac{1}{2} \gamma d^2 \sigma \frac{1}{\sqrt{z^2 + \frac{9}{8} d^2}} \left( \frac{1}{\sqrt{1 + 4\xi}} + \frac{1}{\sqrt{1 - 4\xi}} \right), \tag{19}$$

where

$$\xi = \frac{1}{8} \frac{d^2}{z^2 + \frac{9}{8} d^2}. \tag{20}$$

Rewriting equation (18) gives

$$\bar{g} = \frac{1}{2} \gamma d^2 \sigma \frac{1}{\sqrt{z^2 + \frac{9}{8} d^2}} \frac{2}{\sqrt{1 - \xi}}. \tag{21}$$

Obviously, $\bar{g}'$ gives a better fit to the actual $g$ than $\bar{g}$ does. If, at $P$, $\bar{g} < \bar{g}'$ the gravity discrepancies will tend to cancel each other and $\delta < \delta_{\max}$. Therefore, let us prove that at $P$, $\bar{g} < \bar{g}'$: From equations (19) and (21)

$$\frac{\bar{g}'}{\bar{g}} = \frac{\frac{\sqrt{1 - 4\xi} + \sqrt{1 + 4\xi}}{\sqrt{1 - 16\xi^2}}}{\frac{2}{\sqrt{1 - \xi}}}. \tag{22}$$

Postulating the $\bar{g}' = \bar{g}$ requires that

$$260\xi^4 + 8\xi^3 + 20\xi^2 + \xi = 0. \tag{23}$$

Equation (23) has only two real roots: $\xi = 0$, which requires that $d = 0$ and is therefore trivial; and $\xi \doteq -0.05$, which has no physical meaning, as it requires complex $d$ or $z$. Therefore, $\bar{g}/\bar{g}'$ cannot become unity for any real finite $d$, and if $\bar{g} < \bar{g}'$ in one case, it has to be so in all cases. Now for $z = 0$ and $d = 1$, equation (20) and (22) yield

$$\xi = \frac{1}{9}, \tag{24}$$

and

$$\frac{\bar{g}'}{\bar{g}} = 1.024621 \cdots, \tag{25}$$

therefore,

$$\bar{g}' > \bar{g} \tag{26}$$

quod erat demonstrandum.

Attention shall now be paid to the placement of prisms as suggested in the preceding chapter, step *d*. Table II and Figure 3 show the sequence of the prisms according to the increasing distance, $\rho$, the number of prisms in that ring, and

the number of prisms, $N$, in and inside that ring. Figure 3 shows a little more than the first quadrant of the placement of the prisms.

## METHOD

The method is based on the assumption that the anomalous mass $M$ can be imagined as composed of a finite number, $N$, of vertical prisms. The horizontal dimensions of each prism are small enough, so that within the limits of accuracy the gravity of one prism can be approximated by that of a vertical mass line element at the prism's axis. It can be expressed as a function of depth and horizontal distance by a simple analytical formula. Gravity of the whole mass, $M$, is then computed as an algebraic sum of the contributions of all $N$ prisms at their proper distances and depths. Figures 2 and 5 show the suggested shape and location of a salt dome in the South Timbalier Area, offshore Louisiana, divided into 151 such prisms. The horizontal cross-section of each prism is 2000 by 2000 ft.

TABLE II

SPACING OF PRISMS ON A SQUARE GRID

| Consecutive Number of Ring | Square of distance from center (in spacing units) | Number of Prisms in Ring | $N$ = number of prisms in and inside ring | Consecutive Number of Ring | Square of distance from center (in spacing units) | Number of Prisms in Ring | $N$ = number of prisms in and inside ring |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 26 | 52 | 8 | 169 |
| 2 | 1 | 4 | 5 | 27 | 53 | 8 | 177 |
| 3 | 2 | 4 | 9 | 28 | 58 | 8 | 185 |
| 4 | 4 | 4 | 13 | 29 | 61 | 8 | 193 |
| 5 | 5 | 8 | 21 | 30 | 64 | 12 | 205 |
| 6 | 8 | 4 | 25 | 31 | 65 | 8 | 213 |
| 7 | 9 | 4 | 29 | 32 | 68 | 8 | 221 |
| 8 | 10 | 8 | 37 | 33 | 72 | 4 | 225 |
| 9 | 13 | 8 | 45 | 34 | 73 | 8 | 233 |
| 10 | 16 | 4 | 49 | 35 | 74 | 8 | 241 |
| 11 | 17 | 8 | 57 | 36 | 80 | 8 | 249 |
| 12 | 18 | 4 | 61 | 37 | 81 | 4 | 253 |
| 13 | 20 | 8 | 69 | 38 | 82 | 8 | 261 |
| 14 | 25 | 12 | 81 | 39 | 85 | 16 | 277 |
| 15 | 26 | 8 | 89 | 40 | 89 | 8 | 285 |
| 16 | 29 | 8 | 97 | 41 | 90 | 8 | 293 |
| 17 | 32 | 4 | 101 | 42 | 97 | 8 | 301 |
| 18 | 34 | 8 | 109 | 43 | 98 | 4 | 305 |
| 19 | 36 | 4 | 113 | 44 | 100 | 12 | 317 |
| 20 | 37 | 8 | 121 | 45 | 101 | 8 | 325 |
| 21 | 40 | 8 | 129 | 46 | 104 | 8 | 333 |
| 22 | 41 | 8 | 137 | 47 | 106 | 8 | 341 |
| 23 | 45 | 8 | 145 | 48 | 109 | 8 | 349 |
| 24 | 49 | 4 | 149 | 49 | 113 | 8 | 357 |
| 25 | 50 | 12 | 161 | 50 | 116 | 8 | 365 |
| | | | | 51 | 117 | 8 | 373 |

The inverse problem; namely, to find $F(x, y, z)$ to fit $g(x, y, \sigma)$, does not have a unique solution. However, limitations can be imposed, so that the solution does become unique or at least constrained to a certain range. Such limitations

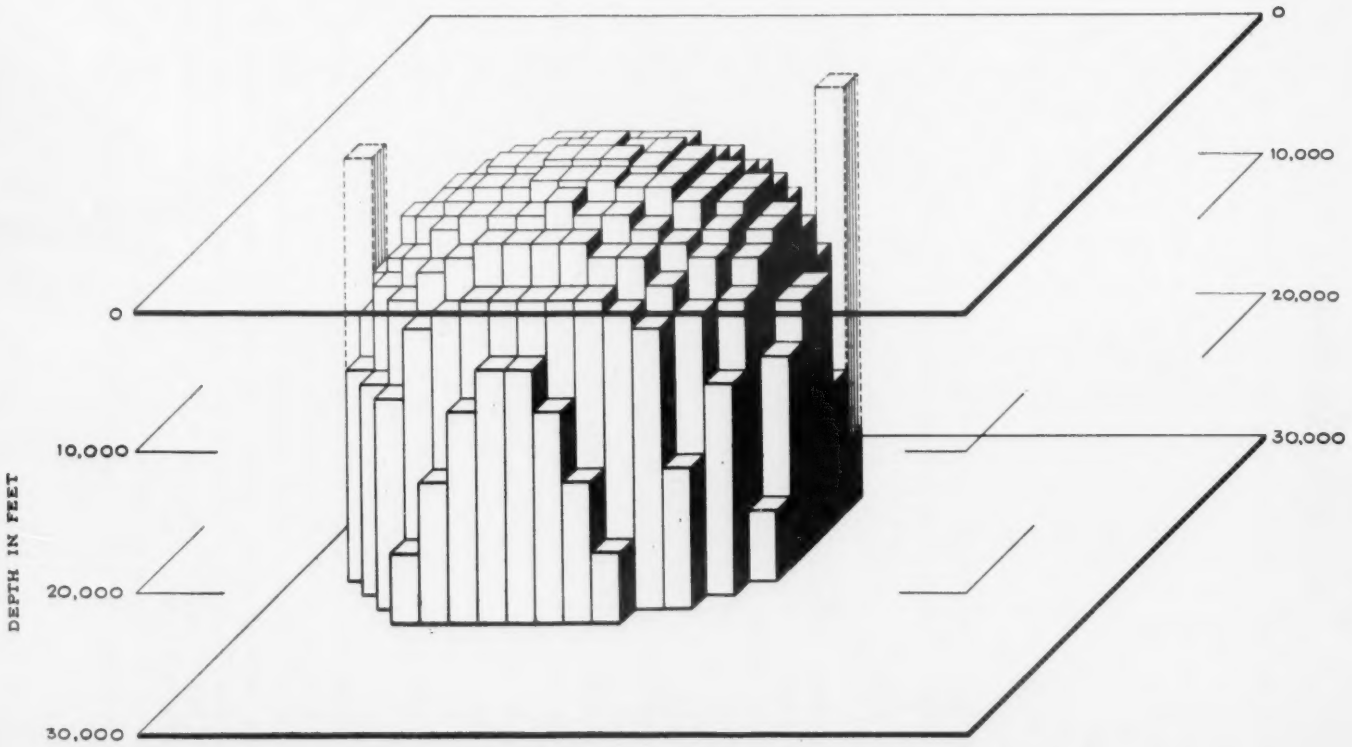



FIG. 2. A salt dome in the South Timbalier area offshore Louisiana represented by a cluster of vertical prisms, $z_B = 30{,}000'$, $d = 2{,}000'$. Two prisms projected on the surface.

may be, for example, a given depth to the mother salt of a salt dome and a postulate that $F(x, y, z)$ be of a certain type; or a given depth to the top (as revealed by drilling, for example) and other restrictions on $F(x, y, z)$.

In the following, a method of successive approximations for deriving the shape of a salt dome is described under the following assumptions and postulates:

1. The bottom of the dome is flat at the depth, $z_B$.
2. $F(x, y, z)=0$, which determines the upper surface of the dome, is a single-valued function of $x$ and $y$ (no salt overhangs).
3. Density contrast between salt and sediments is a logarithmic function of depth, $\sigma=a+b \log_{10} z$, independent of $x$ and $y$.

The solution then consists of the following steps:

(a-1) Find the point, $P_1$, on the residual gravity map, $R_1$, with the highest negative value, $g_1$.

(b-1) Determine the average half width, $H_1$, of the anomaly around $P_1$. This may be done on a digital computer; so that values on the map in four directions; say north, east, south, and west; are compared with $\frac{1}{2}g_1$. If exactly this value is found, its distance from $P_1$ is used with the weight $\frac{1}{4}$. If not, the distances of the nearest two adjacent values, one larger than $\frac{1}{2}g_1$ and the other smaller, are used with the weight $\frac{1}{8}$ each.

(c-1) Find a vertical line element $L_1$ with the bottom at $z_B$, giving approximately the same half width, $\overline{H}_1$. (If $H_1$ is larger than the largest $\overline{H}_1$, use this maximum value of $\overline{H}_1$.) Its top is at $z_{T1}$. The gravity value at the axis of this line element is $\bar{g}_1$.

(d-1) $N=g_1/\bar{g}_1$ is the number of elements $L_1$ necessary to account for $g_1$. Therefore, cluster $N_1$ elements $L_1$ at and around $P_1$, according to the pattern in Figure 3. If $N_1$ is not in the figure, use the next lower number. This cluster represents the first approximation, $A_1$, to the function, $F$.

(e-1) Evaluate the gravity of $A_1$ for all points, $P$, and subtract from the residual values. The map of the differences, $R_2$, is the second residual map and is a measure of the approximation, $A_1$. If $A_1$ is satisfactory, the process is finished. If not, the operation is repeated on $R_2$.

(a-2) Find the point, $P_2$, on map, $R_2$, with the highest negative value, $g_2$.

(b-2) Determine the average half width, $H_2$, of the anomaly around $P_2$ in a way analogous to that described in b-1.

(c-2) Find a line element, $L_2$, with the same or almost the same half width $\overline{H}_2$ in a way analogous to that in c-1. However, the bottom of $L_2$ may be at the top of another prism rather than at $z_B$ if such a prism was required by previous approximation. The top of $L_2$ is at $z_{T2}$. The gravity value at the axis of $L_2$ is $\bar{g}_2$.

(d-2) $N_2=g_2/\bar{g}_2$ is the number of elements, $L_2$, necessary to account for $g_2$. Therefore, cluster $N_2$ elements, $L_2$, at and around $P_2$ in a way analogous to that

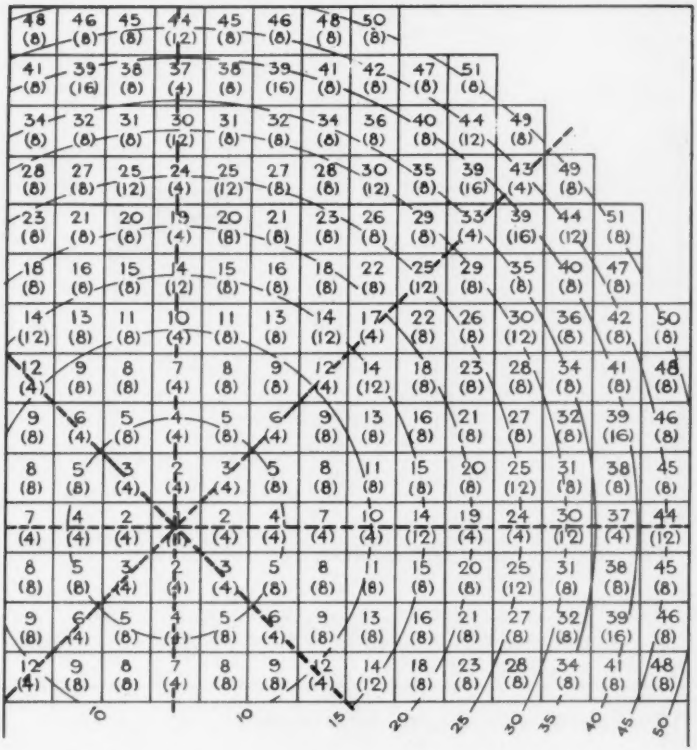



FIG. 3. Spacing of prisms on a square grid, upper number = consecutive number of ring, lower number in parenthesis = number of prisms in the particular ring.

in d-1 but piling them on top of elements previously postulated where necessary. The combination of $A_1$ and the new $N_2$ elements represents the second approximation, $A_2$, to the function, $F$.

(e-2) Evaluate the gravity of $A_2$ for all points, $P$, of the residual map and subtract from the original residual values. The map of the values thus derived, $R_3$, is the third residual map and is a measure of the approximation of $A_2$.

This operation can be iterated until a satisfactory approximation is obtained. An analogous procedure can subsequently be applied on gravity maxima, and pieces of the prisms can be removed. Alternatively, both ways can be used if attention is focused to the point with the highest absolute value of gravity, $|g_i|$, adding or subtracting the prisms according to the sign of $g_i$.

In the ideal case, after $n$ steps, the residual map $R_{n+1}$ would have zero values

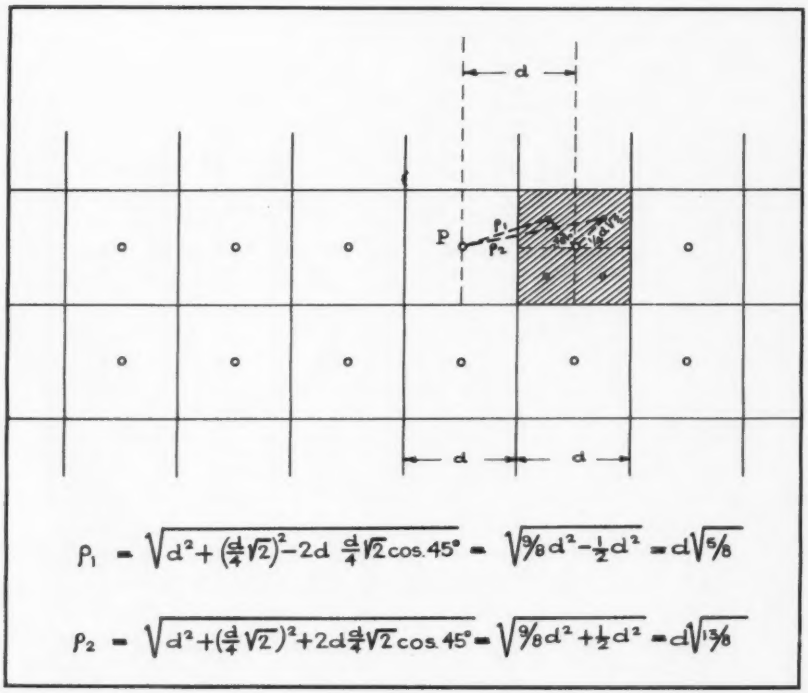



FIG. 4. Gravity effect of a square prism at the axis of an adjacent prism.

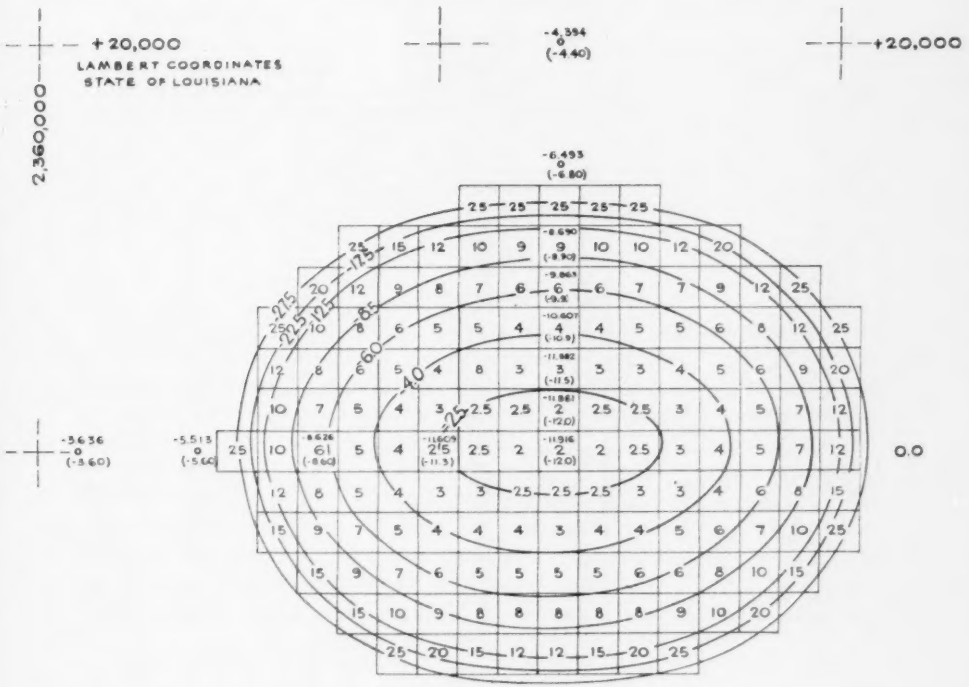
at all points *P*. As this case will hardly ever be achieved, in practice the procedure has to be stopped when a certain degree of approximation is obtained. The criterion depends on the nature of the problem.

## APPLICATION

Part of the method has already been programmed for the IBM-704 computer by Dr. E. Weinberger at the Gulf Research Laboratory, so that gravity effects of a salt dome of a known or assumed shape and density contrast can be determined. Dr. Weinberger also evaluated equation (9) in a tabular form. The method then was tested on the above mentioned dome shown on Figures 2 and 5. Three independent evaluations were performed and are reported in Table III:

1. Evaluation by means of conventional dot charts.
2. Evaluation by means of the table evaluating equation (9).
3. Evaluation by the digital computer.

The same parameters were used in all three evaluations. Results, in general, show good agreement among all three methods. Differences average a few




Assumed Structural Contours on Salt
Depth in Kilofeet
Top View of an Elementary Prism
Depth to Top in Kilofeet
Gravity Evaluation Point
Gravity in milligals from Prism Analysis
Gravity in milligals from Dot Chart Analysis

Over the body of the assumed salt dome, gravity was evaluated for the point at the axis of the particular prism. Bottom of all prisms assumed at 30,000′. Depth contour −17.5 identical with −22.5.

FIG. 5. Gravity of assumed shape of salt dome. South Timbalier area, Offshore Louis.

TABLE III

COMPARISON OF RESULTS OF THE PRISM METHODS AND DOT CHART METHOD
Salt Dome Anomaly 8-6-G, South Timbalier Area, Louisiana

| La. Coordinates of Station | | Calculated Gravity (milligal) | | | Gravity Difference (milligal) | | |
|---|---|---|---|---|---|---|---|
| E | N | Dot Chart | Prism Manually | Prism Computer | Prism Man. Minus Dot Chart | Prism Comp. Minus Dot Chart | Prism Comp. Minus Prism Man. |
| 2,326,000 | 0 | — | − 0.43 | − 0.43 | — | — | 0.00 |
| 2,332,000 | 0 | − 0.50 | − 0.58 | − 0.57 | −0.08 | −0.07 | +0.01 |
| 2,338,000 | 0 | − 0.75 | − 0.80 | − 0.78 | −0.05 | −0.03 | +0.02 |
| 2,344,000 | 0 | − 1.05 | − 1.10 | − 1.10 | −0.05 | −0.05 | 0.00 |
| 2,350,000 | 0 | − 1.58 | − 1.60 | − 1.59 | −0.02 | −0.01 | +0.01 |
| 2,356,000 | 0 | − 2.38 | − 2.37 | − 2.37 | +0.01 | +0.01 | 0.00 |
| 2,362,000 | 0 | − 3.60 | − 3.64 | − 3.64 | −0.04 | −0.04 | 0.00 |
| 2,368,000 | 0 | − 5.60 | − 5.67 | − 5.67 | −0.07 | −0.07 | 0.00 |
| 2,374,000 | 0 | − 8.60 | − 8.63 | − 8.57 | −0.03 | +0.03 | +0.06 |
| 2,380,000 | 0 | −11.30* | −11.14 | −11.16 | +0.16 | +0.14 | −0.02 |
| 2,386,000 | 0 | −12.00 | −11.92 | −11.92 | +0.08 | +0.08 | 0.00 |
| 2,386,000 | 2,000 | −12.00* | −11.86 | −11.86 | +0.14 | +0.14 | 0.00 |
| 2,386,000 | 4,000 | −11.50 | −11.58 | −11.53 | −0.08 | −0.03 | +0.05 |
| 2,386,000 | 6,000 | −10.90 | −10.61* | −10.86 | +0.29 | +0.04 | −0.25 |
| 2,386,000 | 8,000 | − 9.90 | − 9.86 | − 9.93 | +0.04 | −0.03 | −0.07 |
| 2,386,000 | 10,000 | − 8.90 | − 8.69* | − 8.87 | +0.21 | +0.03 | −0.18 |
| 2,386,000 | 14,000 | − 6.80 | − 6.73 | − 6.79 | +0.07 | +0.01 | −0.06 |
| 2,386,000 | 20,000 | − 4.40 | − 4.39 | − 4.39 | +0.01 | +0.01 | 0.00 |
| 2,386,000 | 26,000 | − 2.80 | − 2.86 | − 2.87 | −0.06 | −0.07 | −0.01 |
| 2,386,000 | 32,000 | − 1.95 | − 2.01 | − 1.92 | −0.06 | +0.03 | +0.09 |
| 2,386,000 | 38,000 | − 1.30 | − 1.13* | − 1.31 | +0.17 | −0.01 | −0.01 |
| 2,386,000 | 44,000 | − 0.90 | − 0.85 | − 0.92 | +0.05 | +0.02 | −0.07 |
| 2,386,000 | 50,000 | − 0.65 | − 0.76* | − 0.67 | −0.11 | −0.02 | +0.09 |
| 2,386,000 | 56,000 | − 0.41* | − 0.51 | − 0.50 | −0.10 | −0.09 | +0.01 |
| | | | | | Aver: Algebr. +0.02 | Aver: Algebr. 0.00 | Aver: Algebr. −0.01 |
| | | | | | Scalar 0.08 | Scalar 0.04 | Scalar 0.04 |

* Error Suspected.

hundreds of a milligal and in most cases can be ascribed to errors from rounding off. Differences reaching or exceeding a tenth of a milligal, found in seven cases, are obviously due to occasional errors, as only one evaluation differs, while the other two are in good agreement. Of these errors, the dot chart method seems to involve three; the prism method manually, four; the computer, none.

ACKNOWLEDGMENT

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# HEAT FLOW IN PENNSYLVANIA AND WEST VIRGINIA*

WILLIAM B. JOYNER†

## ABSTRACT

In order to obtain heat-flow values for six wells in Pennsylvania and West Virginia a simple technique was developed for estimating thermal resistivities from well-sample logs. This technique made use of average resistivity values for various categories of sedimentary rocks. The averages were calculated from available resistivity measurements on rock specimens, many of which did not come from the region in which the wells were located. The results indicate that, allowing for error in the estimates, the heat flow at the wells lies between 1.1 and 1.5 microcal/cm² sec. The problem of developing a more accurate technique for estimating resistivity is discussed. Such a technique would be valuable in extending our knowledge of the earth's heat flow.

## INTRODUCTION

A major source of information about the interior of the earth is measurement of the rate at which heat flows out to the surface. A knowledge of heat flow is also important in seeking the causes of crustal deformation. To determine this quantity it is necessary to know both the vertical temperature gradient and the thermal resistivity (the reciprocal of the conductivity) at the same place. Unfortunately, there are few places where both these requirements have been met. In 1954 Birch reviewed the status of geothermal investigations and published a map showing the distribution of reliable heat-flow determinations. Since that time much more work has been done at sea and at least three new measurements have been made on land, but the data are still meager.

Temperature measurements made by Van Orstrand et al of the United States Geological Survey are available for hundreds of wells in this country. There are no cores from these wells for determinations of thermal resistivity, but detailed sample logs have been made for some of them. The present study, originally done in 1953, is an attempt to estimate the resistivity from the sample logs and thereby obtain heat-flow values for six wells in Pennsylvania and West Virginia. It is also hoped that this work will contribute to the development of a general technique for estimating the resistivity of sedimentary rocks. Such a technique would be of considerable help in geothermal studies, since direct measurements of resistivity are possible only where sufficient cores are available.

The wells are listed in Table 1, and Figure 1 shows their locations. Both temperature measurements and sample logs were available for wells no. 1 and 2. For no. 3 through 6 only temperature data were available, and these wells were analyzed with the aid of sample logs from other wells, designated by letters on

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† Humble Oil and Refining Company, Oklahoma City, Oklahoma.

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TABLE 1

LIST OF WELLS

| Well | Name | Operator | County | State |
|---|---|---|---|---|
| 1 | Lehigh Portland Cement Co. No. 1 | Jas. H. Duff and J. T. Galey | Butler | Penn. |
| 2 | Lewis Maxwell No. 11-F | Columbian Carbon Co. | Doddridge | W. Va. |
| 3 | Earl A. Hill No. 1 | Sylvania Corp. | Potter | Penn. |
| 4 | E. N. Clair No. 1 | G. H. Rogers et al. | Potter | Penn. |
| 5 | J. H. Lake No. 1 | Hope Natural Gas Co. | Marion | W. Va. |
| 6 | M. O. Goff No. 1 | Hope Natural Gas Co. | Harrison | W. Va. |

Figure 1. All the wells lie in the Appalachian Plateau province, where the topographic relief is moderate and the beds essentially flat-lying.

## ESTIMATING THERMAL RESISTIVITIES

The key problem lay in estimating the thermal resistivities of the various strata from their descriptions in the logs. This was accomplished by first compiling average resistivity values for different categories of sedimentary rocks. The averages were calculated from measurements made on rock specimens from various localities in the United States and Europe. Descriptions based on microscopic examination were available for all the specimens. As many categories as possible were set up.

The resistivity measurements are given in Table 2 and summarized in Table

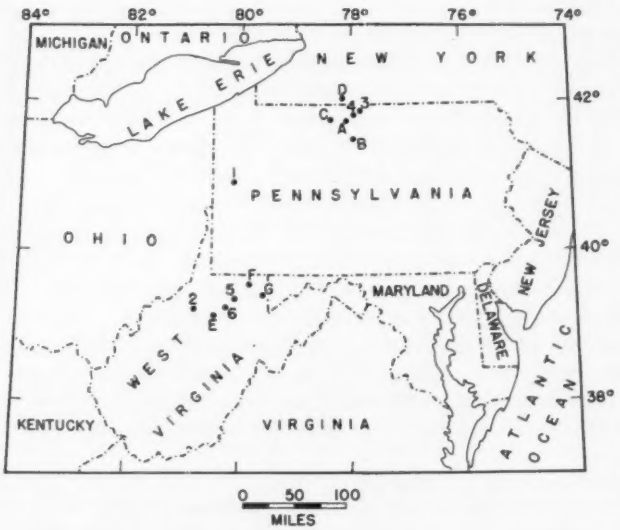


FIG. 1. Index map showing the locations of wells used in the study.

TABLE 2

DATA ON SPECIMENS

| Locality | Thermal Resistivity in cm °C sec/cal | Temperature of Measurement in °C | Porosity in Percent | Density in gm/cm³ | Source |
|---|---|---|---|---|---|
| | | A. QUARTZOSE SANDSTONES | | | |
| Georgia | 80 | 30 | 0.5 | 2.64 | Birch (unpublished) |
| Massachusetts or New York | 87 | 30 | 1 | 2.64 | Birch (unpublished) |
| New York | 94 | 30 | 7 | 2.46 | Birch (unpublished) |
| Colorado | 95 | 30 | 5 | 2.52 | Birch (unpublished) |
| Baltic | 96 | 30 | 6 | 2.49 | Birch (unpublished) |
| ? | 125 | 30 | 26 | 2.02 | Birch (unpublished) |
| Pennsylvania | 92 | 45 | 0.5 | 2.64 | Clark (1941) |
| | | B. IMPURE SANDSTONES | | | |
| Michigan | 168 | 30 | 19 | 2.10 | Birch (unpublished) |
| Pennsylvania | 125 | 30 | 20 | 2.11 | Birch (unpublished) |
| California | 222 | 30 | 16 | 2.23 | Birch (unpublished) |
| California | 149 | 30 | 7 | 2.50 | Birch (unpublished) |
| Pennsylvania* | 120 | 30 | ** | 2.63 | Birch (unpublished) |
| | | C. SANDY SHALES | | | |
| Pennsylvania* | 189 | 30 | ** | 2.76 | Birch (unpublished) |
| Pennsylvania* | 185 | 30 | ** | 2.76 | Birch (unpublished) |
| California | 260 | 30 | 4 | 2.53 | Birch (unpublished) |
| | | D. SHALES | | | |
| Pennsylvania* | 333 | 30 | ** | 2.71 | Birch (unpublished) |
| Pennsylvania* | 278 | 30 | ** | 2.68 | Birch (unpublished) |
| Pennsylvania* | 333 | 30 | ** | 2.55 | Birch (unpublished) |
| Pennsylvania* | 286 | 30 | ** | 2.75 | Birch (unpublished) |
| Pennsylvania* | 250 | 30 | ** | 2.73 | Birch (unpublished) |
| | | E. LIMESTONES | | | |
| Vermont | 151 | 45 | 1 | 2.67 | Clark (1941) |
| Bavaria | 162 | 45 | 3 | 2.30 | Clark (1941) |
| Indiana | 197 | 45 | 13 | 2.61 | Clark (1941) |
| | | F. CALCAREOUS SHALES | | | |
| Pennsylvania* | 204 | 30 | ** | 2.53 | Birch (unpublished) |
| Pennsylvania* | 238 | 30 | ** | 2.49 | Birch (unpublished) |

* From the A. W. Bennet No. 1 well in Sullivan County.
** Not measured.

3. Four were done by Clark (1941) and the rest by Birch (unpublished). The descriptions by which the specimens were classified were made by J. F. Rominger or the writer. In these descriptions the mineral content was estimated; Rosiwal transverses were not made. The "quartzose sandstones" contained more than 95 percent quartz (in all cases chalcedony and chert were lumped together with quartz); the "impure sandstones" had 70 to 90 percent quartz and the remaining material was primarily fine-grained matrix or feldspar; the "sandy shales" contained 20 to 35 percent quartz and no appreciable calcite; the "shales" had less than ten percent quartz, plus calcite; the "limestones" were essentially pure cal-

TABLE 3

AVERAGE THERMAL RESISTIVITIES FOR DIFFERENT ROCK CATEGORIES

| Category | Specimens | Average Resistivity at 30°C in cm °C sec/cal | Range of Resistivity in cm °C sec/cal |
|---|---|---|---|
| Quartzose sandstones | 7 | 95 | 80–125 |
| Impure sandstones | 5 | 157 | 125–222 |
| Sandy shales | 3 | 211 | 189–260 |
| Shales | 5 | 296 | 278–333 |
| Limestones | 3 | 162 | 144–188 |
| Calcareous shales | 2 | 221 | 204–238 |

cite; and the "calcareous shales" contained from 15 to 35 percent calcite and less than five percent quartz. Of course, the statements above do not take account of quartz in particles too fine to be seen with the petrographic microscope, but the fine-grained rocks were tested with hydrochloric acid for the presence of calcite.

During the resistivity measurements all of the specimens were compressed and all of the porous specimens but one were wet (Francis Birch, personal communication; Clark, 1941). Differences between the conditions under which the samples were measured and those prevailing in the wells at depth, except for temperature, are probably not sufficient to cause appreciable error.

The average resistivities in Table 3 were corrected to the temperature in the wells before they were used. The corrections were less than the uncertainty in the resistivity estimates and did not have an important effect on the results. The following formula was used:

$$\text{Resistivity at } T°\text{C} = \text{Resistivity at } 30°\text{C} \times [1+K(T-30)],$$

where $T$ is the centigrade temperature and $K$ the temperature coefficient. For shaley rocks $K$ was given a value of 0.001, for limey rocks and quartzose rocks 0.003. Resistivity temperature curves (Birch and Clark, 1940, p. 554) for a slate, a Solenhofen limestone, and a quartzose sandstone, respectively, were used to obtain the coefficients. The original resistivity measurements on the three limestones had been made at 45°C, and the values given in Table 3 were corrected to 30°C by the above formula. The rest of the measurements, with one exception, had been made at 30°C.

It is difficult to evaluate the uncertainty in this method of estimating resistivities. The uncertainty is probably least in the "shales" and "calcareous shales." The specimens for these two categories were all taken from the A. W. Bennet No. 1 well in Sullivan County, Pennsylvania. While this well is many miles away from the wells in which the temperature measurements were made, the specimens did come from the stratigraphic intervals in which those measurements were taken.

Of the three specimens of "sandy shale," two came from the A. W. Bennett well. One of these, however, is a red shale of the Catskill facies and is not simi-

lar to any of the rocks in which the temperature measurements were made. Estimating the uncertainty for the "sandy shales" is particularly difficult because there are only three samples. This is unfortunate since the heat flow values for the upper intervals in the wells are strongly influenced by the resistivity adopted for "sandy shales."

In each of the other categories the specimens came from scattered localities and represent a wide range of porosity. The spread of resistivity values within each category should therefore be a rough guide to the uncertainty. With two exceptions, all the specimens in these categories have resistivities within 25 percent of the mean.

Everything considered, the writer believes that 25 percent is a safe upper limit for the error in all the categories. An independent check on the error will be presented in the discussion of the results.

## WELL-SAMPLE LOGS

Detailed well-sample logs provided the basic lithologic information. The logs are much too lengthy for reproduction here, but they have all been published elsewhere (see Table 4).

The rocks with which we are concerned lie entirely within the Devonian. Between the top of the Devonian and the top of the Onondaga limestone (Middle Devonian) are four to six thousand ft of shales and sandy shales. This interval is referred to as the "Devonian shales" by Martens (1939, p. 25), who describes the rocks as follows:

"In a general way it may be said that the upper part of the Devonian Shales . . . is gray to greenish-gray and sandy and contains many interbedded thin layers of fine sandstone and siltstone. Going down from the top the amount of sandy material becomes less and the color darker. The basal portion of these shales is black. . . . " In order to distinguish the green, sandy, upper portion from the lower, black shale portion we will use the term "Chemung-type" for the former and "Marcellus-type" for the latter. These names come from formations characteristic of the types. Below the Devonian Shales lies the Onondaga limestone,

TABLE 4

SOURCES FOR WELL-SAMPLE LOGS

| Wells | Source |
|---|---|
| 1 | Martens, 1939, p. 48–53 |
| 2 | Martens, 1939, p. 103–111 |
| A | Fettke, 1949a |
| B | Fettke, 1949b |
| C | Fettke, 1938, p. 119–124 |
| D | Fettke, 1938, p. 137–140 |
| E | Martens, 1939, p. 109–111 |
| F | Martens, 1945, p. 449–455 |
| G | Martens, 1945, p. 471–477 |

which is 20 to 150 ft thick. (The Onondaga is probably the equivalent of what in West Virginia is called the Huntersville chert.) Below that in order come the Oriskany sandstone and the Helderberg limestone, each about 200 ft thick.

The logs for wells no. 1 and 2 (the wells for which we have both temperature measurements and complete logs) were made by examining samples with a binocular microscope and treating them with dilute hydrochloric acid (Martens, 1939, pp. 6–7). Both no. 1 and 2 were drilled with cable tools, and it is therefore unlikely that contamination of samples by caving from above has led to any serious errors in the logs (Martens, 1939, p. 5). In any case, contamination could not have influenced the results from the Marcellus-type shale intervals because the logs describe them as homogeneous. The heat-flow values from the Marcellus-type intervals in wells no. 1 and 2 do not differ significantly from the mean values for those wells. In the other wells only Marcellus-type intervals were used.

All the sandstones within the Devonian Shales were assigned the thermal resistivity of "impure sandstones" (Table 3). There is some direct evidence to support this interpretation. From a microscopic examination Martens (1939, p. 24) described six sandstone samples of the Chemung formation. Their quartz content ranged from 60 to 80 percent. The "impure sandstones" of Table 3 range from 70 to 90 percent. The Bradford Third Sand, which Fettke (1949a, p. 2) calls "sandstone," lies within the Devonian Shales. Kyrnine (1940, p. 55) studied the Bradford Third Sand in detail and described it as follows:

| | |
|---|---|
| 60–65% | individual quart grains |
| 1½% | feldspar |
| 30% | rock fragments (*quartzites*, schists, phyllites, slates) |
| 2–3% | fairly large mica flakes |
| 5–10% | "clay paste." |

There is no guarantee, of course, that the terms "sandy shale," "calcareous shale," etc., were used by those who compiled the well-sample logs in precisely the same sense as they were used in making up Table 3. But, since the categories are quite broad, the error from this source would probably not be large enough to justify raising the estimate of uncertainty above the 25 percent previously decided upon.

Categories intermediate between those listed in Table 3 were necessary in order to make full use of the well-sample logs. Therefore, "very sandy shale" was given a resistivity halfway between that of "impure sandstone" and "sandy shale"; "slightly sandy shale" halfway between "sandy shale" and "shale"; "slightly calcareous shale" halfway between "calcareous shale" and "shale"; and "argillaceous limestone" halfway between "calcareous shale" and "limestone." "Sandy limestone" was assumed to be the equivalent of 30 percent "quartzose sandstone" and 70 per cent "limestone," and its resistivity was an average of the "limestone" resistivity weighted by 0.7 and the "quartzose sandstone" resistivity

weighted by 0.3. Likewise, "calcareous sandstone" was assumed to be 70 percent "quartzose sandstone" and 30 percent "limestone." Chert was treated as the equivalent of macrocrystalline quartz.

In using the logs it was necessary to introduce certain arbitrary rules. "Shale with a little interbedded sandstone" was taken to be 90 percent shale and ten percent sandstone. "Some interbedded sandstone," or just "interbedded sandstone," was interpreted as 20 percent sandstone, "much" or "considerable interbedded sandstone" as 30 percent sandstone, "shale, partly sandy" as 50 percent shale and 50 percent sandy shale. Similar interpretations were made of analogous statements involving other rock types. "Silty shale" was considered to be "slightly sandy shale" and "siltstone" to be "sandy shale." "Shale, partly sandy and silty" was taken as 60 percent "shale" and 40 percent "sandy shale."

The well-sample logs were used in the following manner. For each interval in a well between adjacent temperature measurements a resistivity was determined by weighting the appropriate resistivity value for each bed by thickness and averaging. The temperature gradient was then divided by this resistivity to obtain the flow of heat through the interval. To avoid corrections for topography or climatic history only intervals from depths greater than 1,000 ft were used.

It should be added that, in order to guard against bias in the process of estimating resistivities, the author refrained from analyzing the temperature measurements until all decisions affecting the average resistivity values had been made.

### RESULTS FROM THE FIRST GROUP OF WELLS

Tables 5 and 6 show the results for wells no. 1 and 2. The spread of the individual values is encouragingly small. In Figures 2 and 3 the gradients and heat: flow values for wells no. 1 and 2 are plotted against depth. The gradients show a striking correlation with rock type; the heat-flow values show a corresponding but greatly reduced correlation. For intervals dominated by the Chemung-type rocks

TABLE 5

HEAT FLOW IN WELL NO. 1

| Depth of Interval in feet | Gradient in $10^{-6}$ °C/cm | Average Resistivity in cm °C sec/cal | Heat Flow in microcal/cm² sec |
|---|---|---|---|
| 1000–1500 | 233 | 224 | 1.04 |
| 1500–2000 | 237 | 206 | 1.15 |
| 2000–2500 | 313 | 254 | 1.23 |
| 2500–3000 | 331 | 253 | 1.31 |
| 3000–3500 | 371 | 275 | 1.35 |
| 3500–4000 | 353 | 299 | 1.18 |
| 4000–4500 | 375 | 291 | 1.29 |
| 4500–4809 | 189 | 200 | 0.95 |
| 4809–5000 | 191 | 145 | 1.32 |

mean heat flow (weighted by thickness) 1.20 microcal/cm² sec
standard deviation 10%

TABLE 6

HEAT FLOW IN WELL NO. 2

| Depth of Interval in feet | Gradient in $10^{-6}$ °C/cm | Average Resistivity in cm °C sec/cal | Heat Flow in microcal/cm² sec |
|---|---|---|---|
| 3500–3850 | 224 | 214 | 1.05 |
| 3850–4000 | 243 | 220 | 1.10 |
| 4000–4500 | 295 | 223 | 1.32 |
| 4500–5000 | 313 | 252 | 1.24 |
| 5000–5500 | 270 | 250 | 1.08 |
| 5500–6000 | 361 | 263 | 1.37 |
| 6000–6500 | 411 | 292 | 1.41 |
| 6500–7000 | 197 | 184 | 1.07 |

mean heat flow (weighted by thickness) 1.22 microcal/cm² sec
standard deviation 11%

the heat-flow values are in every case lower than the means. It is probable that the resistivities used for "impure sandstones" and "sandy shales" were too high for these particular rocks.

Any error in the mean heat flow due to errors in temperature measurements is probably negligible compared with the uncertainty in estimating resistivities. That uncertainty was judged to be 25 percent and, on that assumption, the heat flow in wells no. 1 and 2 is $1.2 \pm 0.3$ microcal/cm² sec.

From other considerations, however, it appears that the heat flow cannot be less than 1.1 microcal/cm² sec. The average gradient exceeds $360 \times 10^{-6}$ °C/cm over a 1,500-ft interval in well no. 1 and over a thousand-ft interval in well no. 2. A heat flow less than 1.1 microcal/cm² sec would imply average resistivities

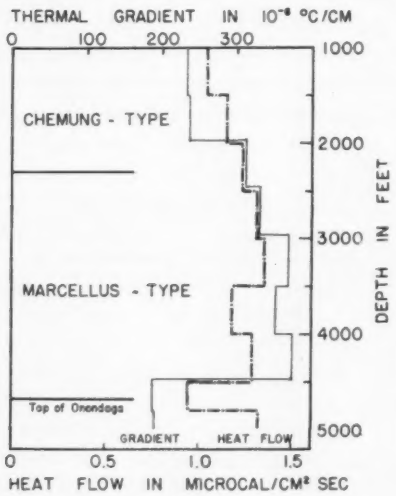


FIG. 2. Thermal gradients and heat flow in well no. 1.

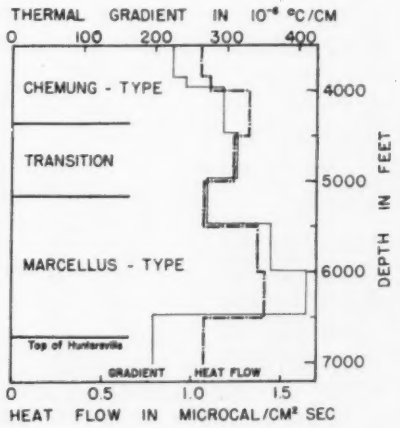


FIG. 3. Thermal gradients and heat flow in well no. 2.

TABLE 7

HEAT-FLOW VALUES IN WELLS NO. 1 AND 2 FROM GROUPS OF INTERVALS DOMINATED BY DIFFERENT LITHOLOGIES

| A. Well | Depth of Interval in feet | Combined percent sandy shale, impure sandstone, and very sandy shale | Heat Flow in microcal/cm² sec |
|---|---|---|---|
| 1 | 1000–1500 | 62.4 | 1.04 |
| 1 | 1500–2000 | 80.2 | 1.15 |
| 2 | 3500–3850 | 61.7 | 1.05 |
| | mean heat flow (weighted by thickness) 1.08 microcal/cm² sec | | |
| **B. Well** | **Depth of Interval in feet** | **Percent shale** | **Heat Flow in microcal/cm² sec** |
| 1 | 3500–4000 | 100.0 | 1.18 |
| 1 | 4000–4500 | 86.2 | 1.29 |
| 2 | 6000–6500 | 70.6 | 1.41 |
| | mean heat flow (weighted by thickness) 1.29 microcal/cm² sec | | |
| **C. Well** | **Depth of Interval in feet** | **Combined percent chert, calcareous chert, cherty limestone, and limestone** | **Heat Flow in microcal/cm² sec** |
| 1 | 4500–4809 | 46.6 | 0.95 |
| 1 | 4809–5000 | 87.4 | 1.32 |
| 2 | 6500–7000 | 58.6 | 1.07 |
| | mean heat flow (weighted by thickness) 1.08 microcal/cm² sec | | |

greater than 330 cm °C sec/cal in these intervals. But the highest resistivity of the five shale specimens (Table 2) was 333 cm °C sec/cal. These specimens were taken from a well in the same region as wells no. 1 and 2, and they came from the same stratigraphic interval as that in which the gradients greater than 360 $\times 10^{-6}$°C/cm were observed.

A further check on the error was made by comparing heat-flow values from intervals dominated by different rock types. Three groups of three intervals apiece were used. In the first group were placed the three intervals with the highest combined percentage of "sandy shale," "impure sandstone," and "very sandy shale," in the second group the three intervals with the highest percentage of "shale," and in the third group the three intervals with the highest combined percentage of "chert," "calcareous chert," "cherty limestone," and "limestone." The results from the third group of intervals are completely independent of the results from the other two. The only relationship between the first group and the second is that two of the three specimens used in obtaining the resistivity of "sandy shale" and all of the specimens of "shale" came from the same well, the A. W. Bennet no. 1. The "shale" specimens, however, were black and nonsandy Marcellus-type rocks from 6,536 ft or deeper, whereas of the two "sandy shales" one was a red shale of the Catskill facies from a depth of 2,360 ft and the other a green Chemung-type rock from 2,345 ft.

Table 7 gives the results from the three groups of intervals; their consistency strengthens the conclusion that the error of the mean values for wells no. 1 and 2 is not greater than 25 percent. From these arguments it is believed that the true heat flow lies between 1.1 and 1.5 microcal/cm² sec.

## RESULTS FROM THE OTHER WELLS

Temperature measurements but no sample logs were available for wells no. 3 through 6. The average resistivities for intervals in these wells were obtained from the sample logs of nearby wells. Intervals were correlated from one well to another by distance above and below the top of the Onondaga limestone (or Huntersville chert). The Marcellus-type shales, because of their lateral uniformity, seemed likely to give the best results, and so only intervals which lay mostly within those shales were used.

TABLE 8

HEAT FLOW IN WELLS NO. 3 THROUGH 6

| Well | Depth of Interval in feet | Gradient in $10^{-6}$ °C/cm | Average Resistivity in cm °C sec/cal | Heat Flow in microcal/cm² sec |
|---|---|---|---|---|
| 3 | 4000–4500 | 368 | 282 | 1.31 |
| 3 | 4500–5165 | 402 | 251 | 1.60 |
| 3 | mean (weighted by thickness) | | | 1.47 |
| 4 | 4000–4500 | 325 | 290 | 1.12 |
| 4 | 4500–5000 | 364 | 264 | 1.38 |
| 4 | 5000–5287 | 368 | 242 | 1.52 |
| 4 | mean (weighted by thickness) | | | 1.31 |
| 5 | 6000–6500 | 386 | 302 | 1.28 |
| 5 | 6500–7000 | 284 | 255 | 1.11 |
| 5 | mean (weighted by thickness) | | | 1.20 |
| 6 | 6000–6500 | 411 | 305 | 1.35 |
| 6 | 6500–7000 | 371 | 305 | 1.22 |
| 6 | 7000–7310 | 306 | 263 | 1.16 |
| 6 | mean (weighted by thickness) | | | 1.26 |
| Mean heat flow for wells no. 3 through 6 (weighted by thickness) | | | | 1.31 |

In wells no. 3 and 4 average resistivities were determined from the sample log for well A, in well no. 5 from the log for well F, and in well no. 6 from the log for well E. As a check on the error involved in using the sample log of another well to termine the average resistivity of an interval, the average resistivities for intervals in well no. 4 were recomputed using the logs from wells B, C, and D and for intervals in well no. 6 using the logs from wells F, G, and no. 2. In no case did the recomputed value differ by more than 12 percent from the original.

The results from wells no. 3 through no. 6 are presented in Table 8. Agreement with the results from the first two wells is satisfactory.

## DEVELOPING A MORE ACCURATE TECHNIQUE FOR ESTIMATING THERMAL RESISTIVITY IN SEDIMENTARY ROCKS

The ideal would be a technique for estimating resistivity within ten percent from observations on samples possibly supplemented by electric, neutron, or velocity logs. Birch and Clark (1940) have accomplished this for igneous rocks

and Herrin and Clark (1956) have for rock salt. To achieve the desired accuracy for other sedimentary rocks more measurements on rock specimens would be necessary. Some information on porosity would also be needed. Linear regression analysis (Figure 4) on the three "limestones" and the six purest of the seven "quartzose sandstones" (Table 2) shows that a ten-percent change in porosity produces a resistivity change of about 25 percent. The porosity information could probably be obtained from analysis of electric logs or, preferably, velocity logs. It might be better to ignore porosity and work instead with the correlation between resistivity and acoustic velocity.

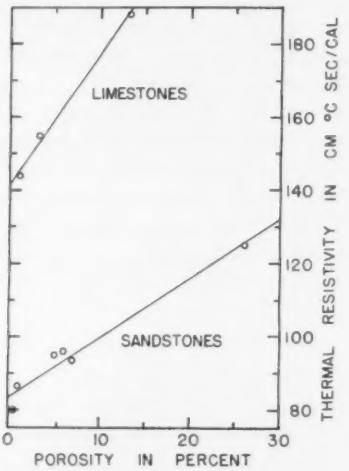


FIG. 4. Thermal resistivity as a function of porosity for three pure limestones and six pure quartzose sandstones.

The resistivities of coarse-grained rocks composed of quartz, calcite, and/or dolomite could probably be estimated within ten percent from their mineral composition and porosity. More measurements on specimens would be needed, but the data on Figure 4 show the feasibility. The intercepts of the straight lines at the zero-porosity axis represent the effective resistivities of calcite and quartz at zero porosity. Using those effective resistivities an attempt was made to predict the resistivity of a nonporous, sandy limestone which contained 40 percent quartz and 60 percent calcite. An average of the effective resistivities weighted by volume percent was computed, and it fell within five percent of the directly measured resistivity. This is essentially the method used by Birch and Clark (1940) for igneous rocks.

Using a similar system the writer tried to predict the resistivities of the "impure sandstones" (Table 2) from their quartz content and porosity. The effort

was a failure. A study is needed of the factors governing resistivity in rocks containing shaley material. X-ray diffraction analysis might help in such a study.

With an accurate technique for estimating resistivity in sedimentary rocks it would be possible to obtain heat-flow determinations at a reasonable cost by making temperature measurements in selected wells after they had been abandoned. Exploration for oil and gas, particularly in recent years, has been expanding to many new areas and provides an opportunity for good geographic coverage of the world.

## CONCLUSIONS

This study showed that the heat flow at the wells investigated probably lies between 1.1 and 1.5 microcal/cm$^2$ sec. More important, it demonstrated the feasibility of getting heat-flow values accurate to better than 25 percent by estimating thermal resistivities from well-sample logs.

With additional measurements on rock specimens and with some porosity information, probably from velocity logs, it should be possible to reduce the error to ten percent or less for coarse-grained rocks composed only of quartz, calcite, and/or dolomite. To achieve such accuracy with the rocks containing shaly material would require a study of the factors governing their resistivity. A technique of estimating the resistivity of sedimentary rocks within ten percent would make heat-flow determinations in abandoned wells possible without the numerous cores now needed.

## ACKNOWLEDGMENTS

The study was suggested by Professor Francis Birch, who read the manuscript and made several valuable suggestions. He also let the writer use numerous unpublished resistivity measurements on rock specimens, including some pieces of core from the A. W. Bennet No. 1 well, Sullivan County, Pennsylvania. These were obtained through the courtesy of Dr. Paul H. Price, Geological and Economic Survey of West Virginia, and Mr. E. M. Kipp, Chief Engineer, the California Company. Many of the specimens on which the measurements were made had been examined by J. F. Rominger, whose descriptions were helpful. Unpublished temperature data were made available by Dr. E. S. Larson, III, and Mr. H. C. Spicer of the United States Geological Survey. The writer's wife, Mary Lou Joyner, edited and typed the manuscript.

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GEOPHYSICS, VOL. XXV, NO. 6 (DECEMBER, 1960), PP. 1242–1250, 5 FIGS.

# MAGNETIC AND TELLURIC CURRENT DISTURBANCES IN ALASKA*

E. M. WESCOTT†

## ABSTRACT

Much of Alaska lies in or near the auroral zone, where magnetic and telluric current disturbances are large compared to those at lower geomagnetic latitudes. Pronounced and different diurnal variations of disturbance are evident from analysis of *K* indices from Barrow, College, and Sitka magnetic observatories. The quietest period for magnetic or electrical surveying is the late morning and afternoon hours locally.

Recordings of telluric current disturbances can be used as a sensitive indicator of ionospheric activity. The large amplitude and rich frequency spectrum of the telluric currents suggests their use as a prospecting tool in Alaska.

## INTRODUCTION

Basic research concerning high latitude ionospheric phenomena is conducted at the Geophysical Institute of the University of Alaska. Certain aspects of this research may prove to be of immediate practical interest to parties considering magnetic or electrical prospecting for oil or minerals in Alaska. In and near the auroral zone hardly a day passes without the occurrence of magnetic and telluric disturbance that would be considered a storm at lower geomagnetic latitudes. Since much of Alaska lies in the zone, exploration programs must be planned with knowledge of ionospheric phenomena.

## DEFINITION AND LOCATION OF THE AURORAL ZONE

The auroral zone is generally defined as that zone or region in either hemisphere where the maximum number of aurorae occur, and is thus an average over some period of time. The area of maximum auroral activity may move north or south on various nights. The auroral zone is known to vary with the seasons, and depends upon sunspot activity. The center of the northern zone varies somewhat with longitude, ranging between 65° and perhaps to more than 70° geomagnetic latitude.

During the IGY a number of all-sky cameras were set up to record the aurorae in Alaska. The films were analyzed for presence and motion of aurora by Davis and Kimball (1960). Figure 1 is a map of Alaska with the geomagnetic coordinates including a curve of the normalized presence of aurora projected along the 256° E geomagnetic longitude line. On the basis of these data the auroral zone projected parallel to the geomagnetic latitudes, lies between College and Barrow centered at about 67°. Whitham and Loomer (1957) who discuss the magnetic activity at Resolute Bay, Baker Lake, and Meanook in Northern Canada, show a map with

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† Geophysical Institute, University of Alaska, College, Alaska.

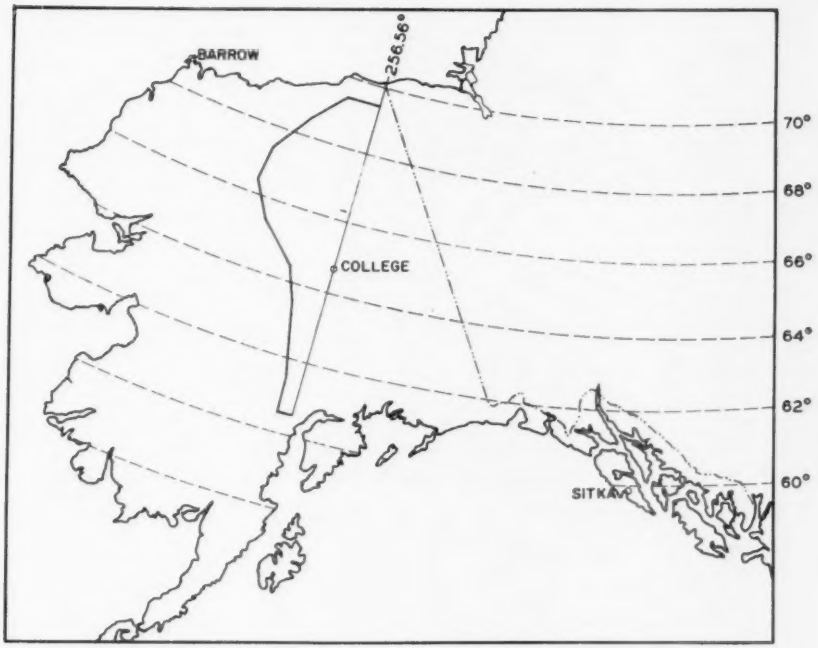


FIG. 1. The normalized presence of aurorae along the 256.56° geomagnetic longitude line.

the center of the zone north of Barrow. Barrow is at a lower geomagnetic latitude than Baker Lake, and Sitka is at about the same latitude as Meanook.

## MAGNETIC DISTURBANCES

The diurnal variation of magnetic disturbance was obtained by analysis of the quasi-logarithmic $K$ indices from the U.S. Coast and Geodetic Survey magnetic observatories at Barrow, College and Sitka.[1] The lower limit for $K=9$ at Sitka is 1,000 $\gamma$, compared to 2500 $\gamma$ at Barrow and College. In order to obtain a true average of the diurnal magnetic activity, the $K$ indices were converted to field intensity in gammas by means of the $K$ to $ak$ index conversion. The eight daily values were averaged on a monthly basis. The monthly averages were also grouped by equinoctial and solstitial periods $e$, $j$, and $d$.

The $K$ indices are readily available, and thus are handy for determining magnetic disturbance patterns, but they are by no means ideal. The $K$ indices are an indication of world wide sudden commencements or solar events which may occur at any time distorting the normal daily disturbance pattern. Since the index rep-

[1] For a description of magnetic indices see Appendix 1.

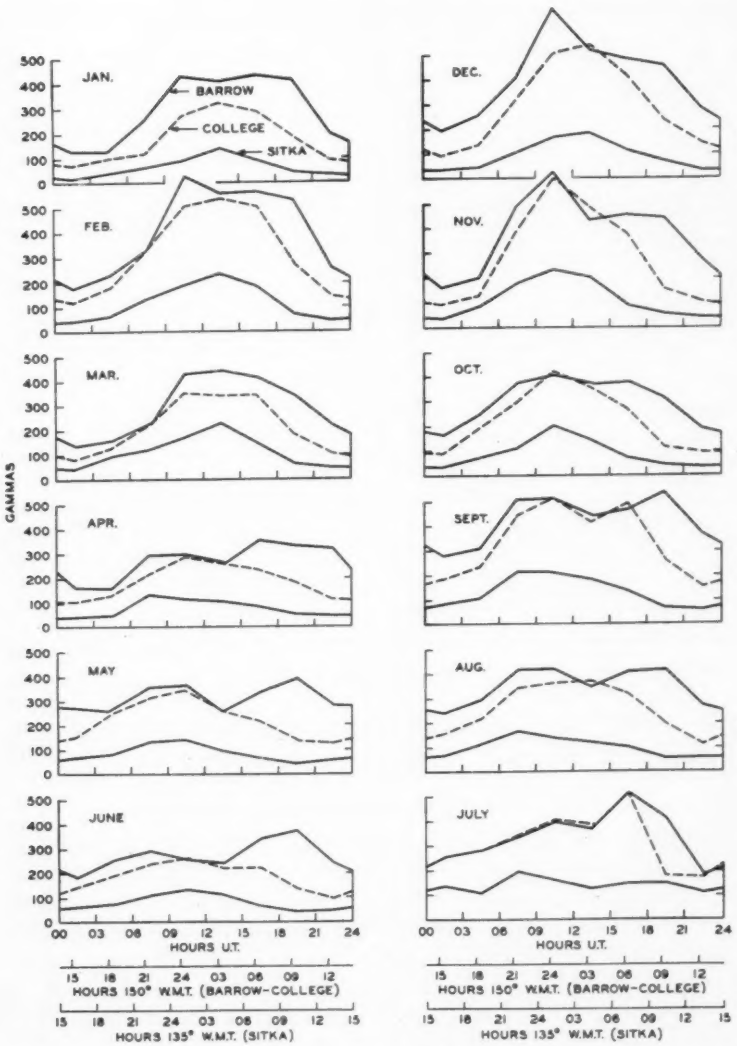


FIG. 2. The diurnal variation of magnetic disturbance for the months of 1959.

resents the maximum range of activity of $H$, $D$, or $Z$ in a three-hour period, one cannot determine which component was the most active. No effort was made to refine the data, but probably the seasonal average curves are little affected by random events.

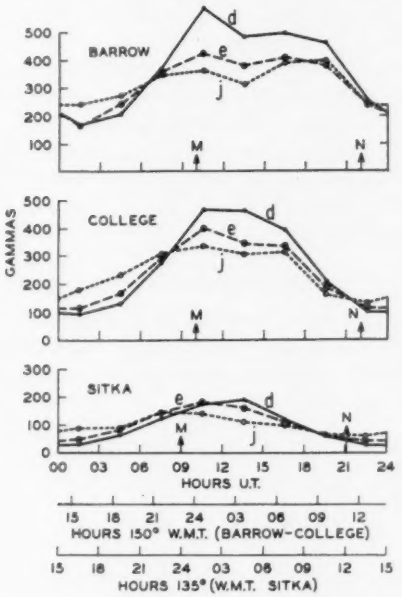


FIG. 3. The dirunal variation of magnetic disturbance for the equinoctial and solstitial periods, 1959.

The effect of smoothing over a three-hour period, makes it very difficult to tell whether the diurnal patterns occur on local or geomagnetic time. Whitham and Loomer (1957) refer the times of maxima in their diurnal curves to geomagnetic noon and midnight, although a replot of these data gives a better fit with local noon and midnight. Because the present study is based on a limited number of stations with small longitude separation, the diurnal curves are referred to local time. In spite of the shortcomings, the *K* index does give a good measure of magnetic activity for a study of magnetic survey problems.

The diurnal curves for Barrow, Figures 2 and 3, show a persistent morning peak during the period 08–11 hours, 150 WMT, corresponding to the predominant daytime peak characteristic of magnetic stations inside the auroral zone (Mayaud (1956)). There is also a nighttime peak of activity centered near local midnight, which is similar to the normal nighttime maximum characteristic of stations below the auroral zone such as Sitka and Meanook. The nighttime maximum varies in amplitude with the seasons, predominating in the winter, and diminishing in the summer. The development of the nighttime peak agrees with the results of Mayaud (1956) and Whitham and Loomer (1957), and suggests that the auroral zone moves north during the winter months.

The diurnal curves at College have a predominant nighttime maximum near local midnight, and activity is high until about 0600 150 WMT. There is very

little indication of a daytime peak. In general the activity at College is less than at Barrow and particularly in the morning hours.

At Sitka the diurnal curve has a single peak which occurs during the nighttime. The amplitude of disturbance is in general about half that of College.

Activity tends to be greatest during the winter months and least during the summer months at all three stations as demonstrated in Figure 3. This result has been verified on the basis of four years of telluric current data at College (Hessler and Wescott 1960). In the auroral zone zone between College and Barrow, one may expect larger disturbances.

## MAGNETIC SURVEYS IN ALASKA

Morley (1953) makes the observation that if corrections from a ground control station are applied to aeromagnetic profiles made during a storm, the flight line must be less than 87 miles from the ground station to have any meaning. Because the form of a magnetic storm varies with distance from a station, a map produced by correcting profiles made during storms would probably be so inaccurate as to be of little use in oil prospecting. For accurate magnetic surveying it seems best to fly only during the quiet periods.

Table 1a

No. of Days in 1959 $K \leq 2$ ($100\gamma$)

| Hours 150 WMT | 02–05 | 05–08 | 08–11 | 11–14 | 14–17 | 17–20 | 20–23 | 23–02 |
|---|---|---|---|---|---|---|---|---|
| College | 95 | 123 | 184 | 228 | 198 | 179 | 139 | 93 |
| Barrow | 42 | 36 | 54 | 81 | 98 | 89 | 85 | 53 |

Table 1b

No. of Days in 1959 $K \leq 4$ ($350\gamma$)

| Hours 150 WMT | 02–05 | 05–08 | 08–11 | 11–14 | 14–17 | 17–20 | 20–23 | 23–02 |
|---|---|---|---|---|---|---|---|---|
| College | 218 | 251 | 314 | 349 | 349 | 323 | 274 | 204 |
| Barrow | 212 | 207 | 206 | 287 | 326 | 306 | 241 | 176 |

Table 1 shows the number of days in 1959, when the magnetic activity was less than 100 $\gamma$, and 350 $\gamma$, in the three hour periods. Data are given only for College and Barrow, as the activity at Sitka is much less overall.

During the quietest hours, about one day in four shows activity less than 100 $\gamma$ at Barrow. One day in two is this quiet at College, while at Sitka most of the days were as quiet at this time. At all stations the afternoon activity was generally less than 350 $\gamma$. On the basis of the average diurnal pattern of disturbance, and the number of quiet days, the best period for conducting surveys is the afternoon hours.

## TELLURIC CURRENT DISTURBANCES

Telluric currents are continuously recorded by the Geophysical Institute at College and Barrow. There is a high degree of correlation between earth currents and magnetic disturbance. At College the telluric currents are generally oriented

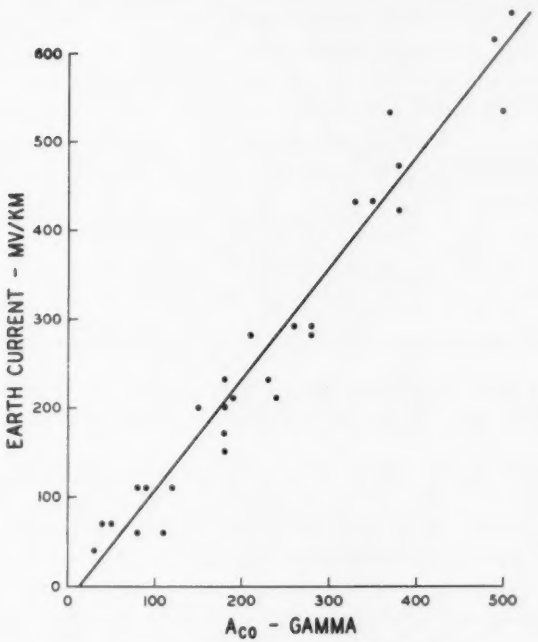


FIG. 4. Scatter diagram and least squares regression line. Telluric current activity versus magnetic activity at College, April 1958.

along a line N 35° W, so for scaling purposes only the N-S component is considered. The telluric current records are scaled for range of activity in mv/km during the same three hour periods as the $K$ indices.

To obtain a measure of the correlation between electric and magnetic activity, the daily average telluric current range in mv/km was compared with the magnetic equivalent daily amplitude $A_{co}$ in gammas. Figure 4, shows the scatter diagram mv/km vs $A_{co}(\gamma)$ for April 1958. The correlation coefficient is 0.975.

The diurnal disturbance variation of telluric currents at College is shown for the three seasons of 1959 in Figure 5. As one would expect the curves are quite similar to the corresponding magnetic curves.

The earth current records show rapid fluctuations of considerable amplitude. During the largest storm at College since 1956, potential gradients greater than 5,000 mv/km were recorded.

## ELECTRICAL PROSPECTING

Due to the large, rapid variations in telluric currents near the auroral zone, prospecting techniques requiring measurements of natural or artificial d.c. potentials may be seriously hampered during storms. From knowledge of the ex-

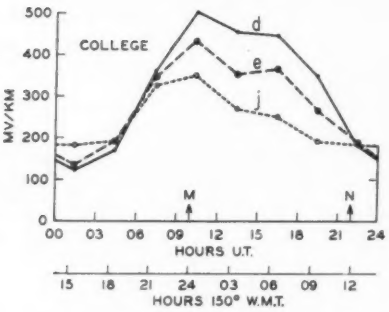


FIG. 5. Diurnal variation of telluric current activity for the solstitial and equinoctial periods, 1959.

pected size of telluric potential disturbances, and the expected accuracy of potential measurements one can determine the feasibility of working during active periods.

The telluric current disturbances of appreciable amplitude at College have periods of about six seconds and longer (Hessler and Wescott 1959). They are often nearly sinusoidal in form, although irregular wave shapes predominate, especially at the longer periods. The large amplitudes, regular occurrence, and rich frequency spectrum of the telluric currents suggests their utilization in telluric or magneto-telluric prospecting in Alaska. Also large areas of flat sedimentary rocks fulfill the requirements of uniform telluric current sheets.

Aside from being a possible nuisance, or aid to electrical prospectors, the telluric currents offer a sensitive indicator of ionospheric activity. All that is required for measuring them is a pair of electrodes in ground free from artificial sources, an amplifier and recorder. Such a recorder can be set up almost anywhere and operated at less expense than a recording magnetometer as an indication of general ionospheric activity.

## CONCLUSIONS

With this present state of knowledge it is not possible to predict magnetic storms very far in advance. Often storms will occur about 48 hours after the observation of a large flare on a favorable location on the sun's surface. At College medium to large storms are often observed to repeat for several nights at about the same time. If a very large storm occurs at night, the next afternoon is quite often disturbed. At each magnetic station a diurnal variation of disturbance is clearly evident, with significant differences between stations. The quietest period occurs locally during the late morning to afternoon hours.

Magnetic and electrical surveying can best be planned with a knowledge of ionospheric activity. Recordings of telluric currents have proven to be a sensitive indicator of activity. The simplicity of recording, makes them a natural aid in planning survey operations near the auroral zone.

ACKNOWLEDGMENTS

This study was supported by the Geophysics Research Directorate of the Air Force Cambridge Research Center. The Magnetic $K$ indices were furnished by the magnetism branch of the U. S. Coast and Geodetic Survey. Thanks is extended to Dr. V. P. Hessler for his help and encouragement in the preparation of this material and to T. N. Davis for the data on the location of the auroral zone.

## APPENDIX 1. MAGNETIC INDICES

Current information on the time variations of geomagnetic activity is given by three parameters for a particular observatory:

1. the three-hour range index, $K$,
2. the daily equivalent amplitude, $Ak$, and
3. the daily character-figure, $C$.

The three-hour range index, $K$, is derived from the records of the three orthogonal field components, for instance $H$, $D$, and $Z$. For each three-hour period, beginning at Greenwich midnight, the range of the disturbance variation in the most disturbed component, is determined with a quasi-logarithmic $K$ scale from 0 to 9. Each observatory specifies the lower limit for $K=9$, and then uses a simple multiple of a normal table to obtain the range limits for the $K$ indices. The normal table is:

| | $K=0$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Range = | 0–5 | 5–10 | 10–20 | 20–40 | 40–70 | 70–120 | 120–200 | 200–330 | 330–500 | 500$\gamma$. |

Thus for College, where the lower limit for $K=9$ is 2500 $\gamma$, the range limits would be multiplied by 5.

To convert a $K$ index reported by an observatory into an equivalent range $ak$, another standard table is used:

| $K=0$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $ak=0$ | 3 | 7 | 15 | 27 | 48 | 80 | 140 | 240 | 400 (2$\gamma$). |

To find $ak$ in gammas for any observatory, this table is multiplied by a factor obtained by dividing the lower limit for $K=9$ by 250. For instance at College the lower limit for $K=9$ is 2,500 $\gamma$, so the factor is 10. Thus for $K=4$ at College, $ak=270$ $\gamma$. The equivalent daily amplitude, $Ak$, is the average of the eight values $ak$ per Greenwich day.

The daily character-figure $C$ is assigned to each Greenwich day on the basis of $C=0$, if it is quiet, $C=1$, if it is moderately disturbed, and $C=2$, if it is heavily disturbed. The method of assigning these characters is left entirely to the discretion of the directors of each observatory.

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# INDEX OF WELLS SHOT FOR VELOCITY*
## (NINTH SUPPLEMENT)

V. U. GAITHER†

ABSTRACT

This is the ninth supplement to the original Index published in the 1944 issue of GEOPHYSICS Information is listed on 340 well velocity surveys not heretofore reported in any previous publication of the Index. Corrections and/or additional information on 5 previously listed surveys are also tabulated.

## INTRODUCTION

This is the ninth supplement to the original "Index of Wells Shot for Velocity," published in the October 1944 issue (Volume IX, Number 4) of GEOPHYSICS. The publication of this supplement was made possible only through the cooperation of the entire geophysical industry, for which the editors of GEOPHYSICS and I wish to express our sincere thanks.

The surveys tabulated in the first portion of this supplement are those shot since the Eighth Supplement (published in the December 1959 Yearbook of Geophysics); also older surveys not reported in previous publications. In the latter portion, shown in italics, are corrections and additional information on previously listed surveys.

It is requested that any errors which may be found in this index be reported to the Business Manager of the Society for correction in subsequent supplements.

The writer is grateful to Mrs. Kathryn B. Smith for her assistance in reconciling and assembling information for this supplement.

* Manuscript received by the Editor September 22, 1960. Copies of this Supplement are obtainable from the SEG Business Office at fifty cents each. Copies of the Fourth, Fifth, Sixth, Seventh and Eighth supplements are also available at fifty cents each.

† Continental Oil Company, Ponca City, Oklahoma.

# INDEX OF WELLS SHOT FOR VELOCITY

## (NINTH SUPPLEMENT)

| *County* | *Company* | *Lease* | *Location* | *Type* | *Survey Depth* | *Shot by* | *Date* | *Sponsored by* |
|---|---|---|---|---|---|---|---|---|
| | | | **STATE OF ARIZONA** | | | | | |
| Apache | Gulf Oil | No. 1 Walker Creek Navajo | 28-41N-26E | Std. Cont. | 6,410 | Empire | 1958 | Gulf |
| Apache | TPC&O et al. | No. 1 Navajo 190 | 20-40N-26E | Std. Cont. | 6,426 | — | 1959 | TPC&O |
| Apache | Texaco | No. Z-1 Navajo Tribe | 36-41N-30E | Std. Cont. | 6,995 | SRS | 1960 | Texaco |
| | | | **STATE OF ARKANSAS** | | | | | |
| Lafayette | Humble | No. 1 Delmar Crank | 34-16S -25W | Std. Cont. | 8,802 | PGAC | 1960 | Group (Humble) |
| Miller | Tennessee Gas | No. 1 J. W. Youngblood | 28-17S -26W | Std. Cont. | 9,985 | SRS | 1960 | TGT Co. |
| Pope | Conoco | No. 1. Sorrels | 28- 8N-18W | Std. Cont. | 6,088 | Century | 1960 | OKWSA (Conoco) |
| | | | **STATE OF CALIFORNIA** | | | | | |
| Colusa | Western Gulf | Strain | 14-13N- 1W | Std. Cont. | 8,822 | Western | 1959 | CWVSG |
| Colusa | Standard | Zumwalt | 14-17N- 3W | Std. Cont. | 6,700 | Western, Schlum. | 1959 | CWVSG |
| Colusa | Humble | W. R. Lynn, et us | 24-16N- 3W | Standard | — | — | 1960 | CWVSG |
| Fresno | Standard | Haven-Boston | 23-20S -18E | Std. Cont. | 14,300 | Western, Schlum. | 1959 | CWVSG |
| Kern | Richfield | K.C.L. "M" | 3-11N-21W | Std. Cont. | 13,960 | SSC | 1959 | CWVSG |
| Kern | Shell | Palla-O'Neil | 19-30S -28E | Std. Cont. | 12,800 | SSC | 1959 | CWVSG |
| Kern | Shell | K.C.L. | 29-11N-21W | Std. Cont. | 13,023 | SSC | 1959 | CWVSG |
| Kern | Richfield | K.C.L. "N" | 23-31S -26E | Std. Cont. | 10,040 | Western, Schlum. | 1959 | CWVSG |
| Kern | Texaco-Standard-Tidewater | Frick | 12-32S -29E | Std. Cont. | 10,910 | Western | 1959 | CWVSG |
| Kern | Honolulu | S.P.L. | 9-31S -28E | Std. Cont. | 12,691 | Shell | 1960 | CWVSG |
| Kings | Ohio | Ohio-Sunray-Westlake Farms | 35-21S -19E | Std. Cont. | 12,024 | United | 1959 | CWVSG |
| Kings | Tidewater | Roswell Richardson | 10-21S -21E | Std. Cont. | 12,675 | G.S.I. | 1959 | CWVSG |
| Los Angeles | Standard | Newhall Land & Farm | 28- 4N-16W | Std. Cont. | 11,962 | SSC | 1959 | CWVSG |
| Merced | Richfield | Ferreira | 26- 6S - 9E | Std. Cont. | 7,334 | SSC | 1959 | CWVSG |
| Solano | Union | Union-Amerada Pedrick | 12- 6N- 1E | Std. Cont. | 7,680 | SSC | 1959 | CWVSG |
| | | | **STATE OF COLORADO** | | | | | |
| Boulder | Texaco | No. B-1 State | 16- 2N-69W | Std. Cont. | 7,985 | SRS | 1959 | Texaco |
| Dolores | Geo. Parker & McCune | Ferris Trail No. 1 | 16-39N-16W | Std. Cont. | 5,907 | Century | 1959 | RMSWSA (PanAm) |
| Larimer | Texaco | No. 1 Warren Livestock | 5-11N-68W | Std. Cont. | 8,190 | — | 1959 | Texaco |
| Moffat | Calco | No. 1 Gov't (Iron Springs Area) | 18-10N-93W | Std. Cont. | 9,343 | SRS | 1959 | RMSWSA (Calco) |
| Moffat | Calco | No. 1 Godiva Unit | 21- 9N-96W | Std. Cont. | 10,770 | SRS | 1959 | RMSWSA (Calco) |
| Montezuma | Calco | Bales No. 1 (House Creek) | 19-39N-14W | Std. Cont. | 8,700 | Empire | 1958 | PanAm |
| Pueblo | Pan American | Katherine Bates Ingham No. 1 | 4-20S -67W | Std. Cont. | 4,490 | SRS | 1959 | RMSWSA (PanAm) |
| San Miguel | Kerr McGee | No. 1 Placerville Unit | 11-43N-11W | Std. Cont. | 6,239 | SRS | 1960 | RMSWSA (Tidewater) |
| Weld | Calco | Grace Wells No. 1 | 17- 7N-67W | Std. Cont. | 8,900 | SSC | 1957 | Calco |
| Weld | Calco | No. 1 Crom | 20- 8N-66W | Std. Cont. | 9,089 | SSC | 1957 | Calco |
| Weld | Chandler-Musgrove | No. 1 Yancy | 13- 6N-67W | Std. Cont. | 9,138 | SSC | 1957 | Calco |
| Weld | Texaco | No. 1 Kurtz | 20- 3N-67W | Std. Cont. | 8,933 | — | 1959 | Texaco |
| | | | **STATE OF FLORIDA** | | | | | |
| Collier | Humble | No. B-2 Gulf Coast Realty | 13-48S -28E | Std. Cont. | 12,075 | SRS | 1960 | Humble |
| Hendry | Commonwealth Dlr. | No. 1 Red Cattle Co. | 23-45S -28E | Std. Cont. | 11,639 | SRS | 1959 | Humble |
| | | | **STATE OF KANSAS** | | | | | |
| Cheyenne | Westheimer & Neustadt | No. 1 Glasco | 10- 1S -38W | Cont. | 4,967 | SSC | 1958 | Phillips |
| Cheyenne | Phillips | No. 1 South St' Francis | 15- 4S -39W | Std. Cont. | 5,500 | SSC | 1958 | Phillips |
| Cheyenne | Iron Drilling Co. | No. 1 Black | 21-22S -26W | Std. Cont. | 4,676 | SSC | 1958 | Phillips |
| Finney | Texaco | No. 1 Davis | 3-23S -30W | Std. Sonic | 4,950 | CXC | 1959 | Texaco |
| Finney | Shell | No. 1 1-17 Stone | 17-26S -33W | Std. Cont. | 5,291 | Magnolia | 1959 | Magnolia |

| *County* | *Company* | *Lease* | *Location* | *Type* | *Survey Depth* | *Shot by* | *Date* | *Sponsored by* |
|---|---|---|---|---|---|---|---|---|
| Grant | Shell | No. 1-26 Fowler | 26-27S -37W | Std. Cont. | 5,712 | Magnolia | 1959 | Magnolia |
| Grant | United Producing Co. | No. 1 C. L. Hickman | 23-30S -35W | Std. Cont. | 5,831 | Magnolia | 1959 | Magnolia |
| Logan | Virginia Drilling | No. 1 Janne | 1-13S -34W | Cont. | 4,606 | SSC | 1959 | Phillips |
| Rawlins | Jackson-Shear-Parker | No. 1 Ruda | 14- 4S -33W | Cont. | 4,661 | SSC | 1958 | Phillips |
| Rawlins | United Cuban, Inc. & Carter | No. 1 Henry | 27- 5S -34W | Cont. | 4,920 | SSC | 1958 | Phillips |
| Sherman | Phillips | No. 3 Shermanville | 21- 6S -38W | Cont. | 5,445 | SSC | 1958 | Phillips |
| Sherman | Phillips | No. 1 Goodland (Thompkins) | 7-10S -39W | Cont. | 5,790 | SSC | 1958 | Phillips |
| Sherman | Phillips | No. 3 Goodland Corehole | 31- 9S -39W | Cont. | 5,331 | SSC | 1957 | Phillips |
| Sherman | Phillips | No. 5 Goodland | 11- 9S -37W | Cont. | 5,644 | SSC | 1958 | Phillips |
| Sherman | Phillips | No. 6 Goodland | 29- 8S -38W | Cont. | 5,520 | SSC | 1958 | Phillips |
| Sherman | Phillips | No. 1 Llanos | 10- 6S -37W | Cont. | 4,937 | SSC | 1958 | Phillips |
| Sherman | Musgrove Petr. Co. | No. 1 Van Donge | 31- 9S -38W | Cont. | 5,845 | SSC | 1957 | Phillips |
| Stanton | Pan American | No. 1 Lindsley | 22-30S -40W | Std. Cont. | 5,448 | — | 1959 | PanAm |
| Thomas | J. S. Carter | No. 1 Foster | 6- 7S -31W | Cont. | 4,962 | SSC | 1958 | Phillips |
| | | | STATE OF LOUISIANA | | | | | |
| Acadia | Union Prod. Co. | No. 1 Beaugh | 83- 8S - 2E | Std. Cont. | 15,135 | SRS | 1960 | Union |
| Calcasieu | Humble | No. 1 Industrial Lbr. Co. | 29- 8S -11W | Std. Cont. | 8,508 | Birdwell | 1960 | Humble |
| Cameron | Magnolia | No. 1 Miami Corporation | 8-14S - 7W | Std. Cont. | 12,782 | Mag.-SSC | 1959 | SSWSA (Magnolia) |
| Cameron | Pan American | State Lease No. 2966 | 21-15S -14W | Std. Cont. | 13,540 | SSC | 1958 | PanAm |
| Cameron | Sunray | No. 1 G. C. Rutherford | 29-14S - 7W | Std. Cont. | 13,996 | SSC | 1960 | Sunray |
| Cameron | Tidewater | No. B-1 Lacassine | 8-12S - 5W | Std. Cont. | 17,208 | Birdwell | 1960 | SSWSA (Tidewater) |
| Iberia | Magnolia | St. Lease 3320 | East Cote Blanche Bay T17S-R7E | Std. Cont. | 16,180 | Magnolia | 1959 | Magnolia |
| Iberia | Humble | No. 1 State Lease 3498 | T17S-R7E | Std. Cont. | 14,200 | Birdwell | 1959 | Humble |
| Jefferson | Calco | No. 2 LL & E 5 | T19S-R24E | Standard | 12,950 | Evangeline | 1958 | Calco |
| Jefferson Davis | Magnolia | No. C-1 J. M. Pettijean | 7-11S - 4W | Cont. | 10,206 | Magnolia | 1959 | Magnolia |
| Lafayette | Conoco | No. 1 Romain Dominque | 14- 9S - 3E | Std. Cont. | 14,500 | SRS | 1959 | Conoco |
| Lafourche | Humble | No. 1 City of New Orleans, et al. | 21-21S -23E | Std. Cont. | 14,502 | SRS | 1959 | Humble |
| Lafourche | Humble | No. 1 State Lease 3446 | T18S-R23E | Std. Cont. | 12,385 | SSC | 1959 | Humble |
| Lafourche | Magnolia | No. 1 Alfred J. Boudreaux | 111-15S-17E | Std. Cont. | 13,660 | SSC | 1959 | Magnolia |
| Lafourche | Humble | No. 4 State Lease 1452 | T22S-R21E | Std. Cont. | 14,100 | SRS | 1959 | Humble |
| Lafourche | Humble | No. 1 State Lease 3419 | 14-21S -23E | Std. Cont. | 16,718 | SRS | 1959 | Humble |
| Lafourche | Humble | No. 1 TP-1 Oil Unit 17 | 25-17S -22E | Std. Cont. | 11,290 | Birdwell | 1960 | Humble |
| Lafourche | Humble | No. 1 TP-1 Oil Unit 10 | 30-17S -23E | Std. Cont. | 12,334 | Birdwell | 1960 | Humble |
| Lafourche | Humble | No. 1 E. B. Green | 15-16S -19E | Std. Cont. | 13,318 | SRS | 1960 | Humble |
| Lafourche | Humble | No. 15 Delta Securities | 34-18S -20E | Std. Cont. | 11,866 | PGAC | 1960 | Humble |
| Ouachita | Sunray | No. 1 E. O. Brooks | 15-18N- 1E | Std. Cont. | 9,703 | SSC | 1958 | Calco |
| Plaquemines | Calco | State Lease 3381 No. 1 | T16S-R16E, Pintail Point | Std. Cont. | 10,489 | SSC | 1959 | Calco |
| Plaquemines | John W. Mecom | No. 3 Vermillion Bay Land Co. | 14-18S -25E | Standard | 13,770 | — | 1959 | Mobil |
| Plaquemines | Humble | No. 1 John Cutrone | 38-17S -14E | Std. Cont. | 12,616 | SRS | 1959 | Humble |
| Richland | Atlantic | No. 1 J. R. Aycock | 7-18N- 8E | Std. Cont. | 9,127 | SSC | 1958 | Atlantic |
| St. Bernard | Humble | No. 1 Lake Eugenie Land & Dev. Co. | 1-16S -17E | Std. Cont. | 9,235 | SRS | 1960 | Humble |
| St. Mary | Humble | M-7 Miami Corporation | 25-16S - 9E | Std. Cont. | 14,020 | SSC | 1959 | Humble |
| St. Mary | Magnolia | No. B-1 State Lease 692 | Blk. 120 Offshore Eugene Is. | Standard | 8,038 | Magnolia | 1959 | Magnolia |
| St. Mary | Atlantic | No. E-1 Adeline Sugar Factory | 55-14S - 9E | Std. Cont. | 13,490 | SSC | 1958 | Atlantic |
| St. Mary | Sunray | No. 1 State Lease 3502 | Atchafalaya Bay | Std. Sonic | 12,990 | Birdwell | 1959 | Sunray |
| St. Mary | Humble | No. 1 State Lease 3520 | Eugene Is., Blk. 4 | Std. Cont. | 14,091 | Empire | 1959 | Humble |
| St. Mary | Quintana | No. 2 Williams, Inc. | 25-15S - 9E | Std. Cont. | 13,602 | SRS | 1960 | Humble |
| St. Martin | Pan American | No. 1 J. E. Broussard Unit | 64- 8S - 6W | Std. Cont. | 11,584 | SSC | 1959 | PanAm |
| St. Tammany | Tommy Neal | No. 1 Keller-Plauche | 9- 9S -13E | Std. Cont. | 10,545 | Magnolia | 1959 | Magnolia |
| Terrebonne | Texaco | No. 1-A State Lease 2856 | T23S-R19E Terrebonne Bay | Std. Cont. | 16,268 | SSC | 1957 | Texaco |
| Terrebonne | Humble | No. D-5 Laterre Co., Inc. | 7-20S -20E | Std. Cont. | 16,006 | SSC | 1959 | Humble |
| Terrebonne | Humble | No. D-6 Continental Land & Fur | 14-18S -12E | Std. Cont. | 11,006 | SSC | 1959 | Humble |
| Terrebonne | Mobil | No. 1 Terrebonne State Lease | 16-18S -12E | Std. Cont. | 13,476 | — | 1959 | Mobil |

| *County* | *Company* | *Lease* | *Location* | *Type* | *Survey Depth* | *Shot by* | *Date* | *Sponsored by* |
|---|---|---|---|---|---|---|---|---|
| Terrebonne | Calco | No. 1 M. S. Nelson | 2-21S -12E | Std. Cont. | 13,854 | SSC | 1959 | Calco |
| Terrebonne | Calco | No. 8 Laterre Co. Inc. | 13-19S -14E | Std. Cont. | 14,226 | SSC | 1959 | Calco |
| Terrebonne | Humble | No. 5 Lutcher-Moore | 56-16S -15E | Std. Cont. | 15,499 | Birdwell | 1960 | Humble |
| Vermilion | Pan American | No. 1 Paul Herpin | 11-11S - 1E | Std. Cont. | 15,475 | SSC | 1958 | PanAm |
| Vermilion | Texaco | No. 1 Edier Bares | 34-11S - 4E | Std. Cont. | 14,994 | — | 1959 | Texaco |
| Vermilion | Sohio | Paul Simon Bracquet No. 1 | 4-12S - 2E | Std. Cont. | 17,286 | Birdwell | 1960 | SSWSA (Sohio) |
| Vermilion | Humble | No. 1 State Lease 3511 | Blk. 13, Vermilion | Std. Cont. | 14,483 | Birdwell | 1959 | Humble |
| Vermilion | Humble | No. 2 State Lease 3055 | 7-15S - 1W | Std. Cont. | 14,164 | Empire | 1959 | Humble |
| Vernon | Jett Drilling Co. | Central Coal & Coke Corp. No. 1 | 30- 3N-10W | Std. Cont. | 11,496 | Magnolia | 1959 | SSWSA (Magnolia) |
| | | | STATE OF MISSISSIPPI | | | | | |
| Amite | Fred D. Meyer, et al. | No. 1 Estelle Brumfield, et al. | 32- 4N- 4E | Std. Cont. | 11,394 | Empire | 1960 | Sunray |
| Clark | Southwest Gas | No. 1 Masonite Corp. | 18- 1N-15E | Std. Cont. | 13,796 | — | 1959 | Mobil |
| Covington | Gulf Coast Dlr. & Expl. | No. 1 Weeks | 18- 9N-16W | Std. Cont. | 14,216 | SRS | 1959 | Humble |
| Franklin | Shortridge & Jett Dlg. | No. 1 Temple | 15- 5N- 5E | Std. Cont. | 11,229 | — | 1959 | Mobil |
| Franklin | Serio-Punches-Billups, La Grange | No. 1 U. S. A. | 18- 6N- 5E | Std. Cont. | 10,834 | SRS | 1960 | Humble |
| Franklin | J. C. Maxwell | No. 1 Central Lbr. Co. | 14- 7N- 3E | Std. Cont. | 10,906 | SRS | 1959 | Humble |
| Hancock | Marshall R. Young | No. 1 Jordan Acres | 34- 7S -15W | Std. Cont. | 10,810 | PGAC | 1960 | Humble |
| Hinds | Magnolia | Jett No. 1 Bridgers | 2- 3N- 2W | Std. Cont. | 13,320 | Empire | 1959 | Magnolia |
| Hinds | Magnolia | No. 1 Randolph Smith | 20- 4N- 1W | Std. Cont. | 12,170 | — | 1959 | Mobil |
| Jasper | Kern Co. Land Co. | No. 1 Harvey Gilmore | 9- 2N-13E | Std. Cont. | 13,285 | Empire | 1959 | K.C.L.C. (Group) |
| Jones | Sinclair | No. 1 Masonite Corp. | 15- 9N-10W | Std. Cont. | 15,000 | SSC | 1959 | Group (Sinclair) |
| Jones | Humble | No. E-1 Masonite Corp. | 2- 6N-12W | Std. Cont. | 13,200 | SRS | 1960 | Humble |
| Lamar | Southern Natural | No. 1 Bass | 36- 2N-14W | Standard | 10,750 | Century | 1960 | Sunray |
| Lincoln | Vasser & Brown Dlg. Co. | No. 1 Brister | 10- 5N- 8E | Std. Cont. | 10,996 | Empire | 1959 | SSWSA (Atlantic) |
| Lincoln | Vasser & Brown | No. 1 Molly Price, et al. | 18- 5N- 8E | Std. Cont. | 11,000 | SRS | 1959 | Humble |
| Marion | Humble | No. C-4 E. A. Ball | 20- 2N-14E | Std. Cont. | 12,607 | SRS | 1959 | Humble |
| Pearl River | Eubanks-Copeland-Anderson | No. 1 Crosby Southern Minerals | 35- 1S -14W | Std. Cont. | 11,007 | Magnolia | 1959 | Magnolia |
| Pike | Calco-Tidewater | No. 1 L. B. Felder | 32- 4N- 9E | Std. Cont. | 10,950 | Empire | 1959 | Calco |
| Rankin | Carter | No. 1 R. A. Kennedy | 13- 3N- 5E | Std. Cont. | 12,384 | Empire | 1959 | Carter (Group) |
| Walthall | Sun | No. 1 J. O. McDonald | 26- 3N-11E | Std. Cont. | 13,888 | PGAC | 1960 | Humble |
| Walthall | Humble | No. 1 Dexter Gas Unit 2 | 8- 1N-13E | Std. Cont. | 11,196 | SRS | 1960 | Humble |
| Warren | Humble | No. 1 R. Lee Parker | 24-14N- 1E | Std. Cont. | 12,513 | Empire | 1960 | Humble (Carter Div) |
| Wayne | American Petroleum | No. 1 G M & O | 35- 8N- 8W | Std. Cont. | 13,026 | Empire | 1959 | Humble |
| Wayne | Drlg.-Expl.-Skelly | No. 1 Mattie Gray | 9- 9N- 6W | Std. Cont. | 11,000 | — | 1959 | SSWSA (Magnolia) |
| Wayne | T P C & O | No. A-1 U. S. A. | 25- 7N- 9W | Std. Cont. | 13,600 | — | 1959 | T P C & O |
| | | | STATE OF MONTANA | | | | | |
| Garfield | Atlantic | NP 33 No. 1 | 33-15N-37E | Std. Cont. | 7,955 | SSC | 1960 | RMSWSA (Atlantic) |
| Glacier | Salt Dome Production | No. 2 Moberly | 1-37N- 5W | Std. Cont. | 4,914 | SSC | 1960 | RMSWSA (Salt Dome) |
| Powder River | Calco | No. 1 Government | 13- 9S -45E | Std. Cont. | 5,710 | SSC | 1958 | Calco |
| Prairie | Ohio | No. 1 Govt. Cranston | 31-12N-49E | Std. Cont. | 9,100 | SSC | 1959 | RMSWSA (Ohio) |
| Roosevelt | Carter | Soo Tribal No. 1 | 8-32N-52E | Std. Cont. | 10,828 | SSC | 1959 | RMSWSA (Carter) |
| Roosevelt | Juniper Oil & Min. Co. | No. 1 Masters | 19-31N-54E | Std. Cont. | 11,037 | SSC | 1959 | RMSWSA (Carter) |
| Sheridan | Mobil Producing | No. F-44-20 P Mueller | 20-32N-59E | Std. Cont. | 12,021 | Birdwell | 1959 | RMSWSA (Mobil) |
| Teton | Conoco | No. 1 State (Scapegoat-Bannatyne Area) | 2-25N- 1E | Std. Cont. | 3,630 | SSC | 1959 | RMSWSA (Conoco) |
| Yellowstone | Texaco | No. 1 Horsky-Ft. | 23- 6N-33E | Std. Cont. | 8,013 | SSC | 1958 | RMSWSA (Texaco) |
| | | | STATE OF NEBRASKA | | | | | |
| Dundy | J. K. Wadley | No. 1 Clegg | 29- 3N-40W | Std. Cont. | 4,600 | Birdwell | 1959 | RMSWSA (Ohio) |
| Grant | T S I | No. 1 Lowe | 1-23N-38W | Std. Cont. | 4,068 | SSC | 1958 | RMSWSA (Tex. Seabd) |
| Sheridan | T S I | No. 1 Musser-Mosler | 10-26N-42W | Std. Cont. | 4,613 | SSC | 1958 | Texaco-Seaboard |

| County | Company | Lease | Location | Type | Survey Depth | Shot by | Date | Sponsored by |
|---|---|---|---|---|---|---|---|---|
| | | | STATE OF NEW MEXICO | | | | | |
| Chaves | Magnolia | No. 1 R. O. Pearson | 23-15S -25E | Std. Cont. | 7,720 | Magnolia | 1959 | Magnolia |
| Chaves | Sohio | No. 1 Monterey Federal | 27-12S -30E | Std. Cont. | 10,330 | Empire | 1959 | Sohio |
| Chaves | Jake L. Hammon | No. 1 Salisbury | 6- 8S -29E | Std. Cont. | 7,392 | — | 1959 | Mobil |
| Eddy | Sunray | No. 1 State "Q" | 32-19S -29E | Std. Cont. | 12,308 | Empire | 1960 | Sunray |
| Eddy | Phillips | No. 1 Seven River's Hills Unit | 5-21S -25E | Std. Cont. | 10,640 | — | 1959 | Mobil |
| Eddy | Shell | No. 1 Henshaw Deep Unit | 24-16S -30E | Std. Cont. | 13,061 | SRS | 1960 | Shell |
| Eddy | Humb'e | No. 1 Bandana Point Unit | 13-23S -23E | Std. Cont. | 12,256 | SRS | 1959 | Humble |
| Lea | Phillips | No. 4 Leamex | 17-17S -33E | Standard | 13,000 | SSC | 1945 | Phillips |
| Lea | Sohio | No. 1 N. Mescaliro | 9-10S -32E | Std. Cont. | 12,149 | SRS | 1959 | Sun |
| Lea | Conoco | No. 10 Sanderson A-14 | 14-20S -36E | Std. Cont. | 9,434 | SRS | 1959 | NMFU (Conoco) |
| Lea | Conoco | No. B-41 Wm. Mitchell | 19-17S -32E | Std. Cont. | 14,250 | SRS | 1960 | Conoco |
| Lea | TPC & O—Pure | No. 1 State "W" | 28-18S -36E | Std. Cont. | 12,240 | — | 1958 | T P C & O |
| Lea | Conoco | No. 1 North Hobbs Unit | 13-18S -37E | Std. Cont. | 8,876 | SRS | 1960 | Conoco |
| Lea | Conoco | No. 6 Bell Lake | 6-23S -34E | Std. Cont. | 15,711 | SRS | 1960 | Conoco |
| Lea | Shell | No. 1 Matlock Federal | 24-19S -34E | Std. Cont. | 6,188 | SRS | 1959 | Shell |
| Lea | Shell | No. 2 H. S. Record | 35-19S -35E | Std. Cont. | 14,091 | SRS | 1959 | Shell |
| Lea | Shell & Texas Crude | Big Eddy Unit No. 1-21 | 21-20S -32E | Std. Cont. | 7,805 | SRS | 1960 | Shell |
| Lea | Gulf | Monument Unit No. 1 | 19-19S -37E | Std. Cont. | 10,928 | SRS | 1960 | Shell |
| Lea | Shell | Hudson Federal No. 1 | 26-20S -33E | Std. Cont. | 3,466 | Empire | 1960 | Shell |
| Lea | Nearburg & Ingram | No. 1 Ohio-State | 16-19S -38E | Std. Cont. | 9,886 | PGAC | 1960 | Shell |
| Roosevelt | Atlantic | No. 1 Pebworth | 25- 8S -36E | Std. Cont. | 12,785 | Empire | 1958 | Atlantic |
| San Juan | Humble | No. 1 Navajo Tribal "H" | 4-31N-18W | Std. Cont. | 8,230 | SRS | 1960 | Humble |
| Valencia | Richard King | No. 1 Wilson Heirs | 14- 7N- 3W | Std. Cont. | 3,988 | SSC | 1958 | Texaco |
| | | | STATE OF NORTH DAKOTA | | | | | |
| Billings | Calco | No. 1 Gov't. | 20-137N-102W | Std. Cont. | 9,120 | Schlum-Century | 1959 | RMSWSA (Calco) |
| Bottineau | Williamson | No. 1 Henning | 22-159N- 81W | Std. Cont. | 4,849 | SSC | 1957 | Calco |
| Burke | Calco | No. 1 Bryant | 29-159N- 90W | Std. Cont. | 8,050 | SSC | 1957 | Calco |
| Dunn | Pan American | No. 1 Jacob Huber | 15-145N- 91W | Std. Cont. | 11,000 | SRS | 1960 | RMSWSA (PanAm) |
| Dunn | Stewart Petroleum | No. 1 Dvirnak | 20-146N- 96W | Std. Cont. | 12,600 | Birdwell | 1960 | RMSWSA (Gulf) |
| Montrail | Calvert-Williamson | No. 1 Salo | 19-157N- 90W | Std. Cont. | 8,430 | SSC | 1957 | Calco |
| Montrail | Calvert-Williamson | No. 1 Bratlien | 9-158N- 92W | Std. Cont. | 8,738 | SSC | 1957 | RMSWSA (Calco) |
| Renville | Anschutz | No. 1 Christianson | 7-158N- 81W | Std. Cont. | 6,961 | SSC | 1959 | RMSWSA (Calco) |
| Stark | Atlantic | No. 1 Anton Eberts | 18-138N- 97W | Cont. | 9,200 | Birdwell | 1959 | RMSWSA (Atlantic) |
| Ward | Hanlon-Williamson | No. 1 Enget | 8-158N- 87W | Std. Cont. | 6,870 | SSC | 1957 | Calco |
| Ward | Hanlon | No. 1 Knudtson | 7-157N- 87W | Std. Cont. | 6,706 | SSC | 1957 | Calco-PanAm |
| Ward | British-American | No. C-1 Anderson | 2-157N- 82W | Std. Cont. | 4,900 | SSC | 1958 | British-American |
| | | | STATE OF OKLAHOMA | | | | | |
| Alfalfa | Conoco | No. 1 Ida Fellers | 1-27N-12W | Std. Cont. | 5,957 | SRS | 1959 | Conoco |
| Alfalfa | Gulf | No. 1 Bentley | 21-24N-13W | Std. Cont. | 7,504 | SRS | 1960 | OKWSA (Gulf) |
| Beaver | Phillips | No. 1 Trice | 35- 2N-2 E | Cont. Sonic | 8,540 | SRS | 1958 | Phillips |
| Blaine | Sunray | No. 1 A. O. Baker "A" | 31-14N-12W | Std. Cont. | 12,216 | SRS | 1960 | — |
| Caddo | Howell Holloway & Howell | No. 1 Anadarko Basin | 4- 9N-12W | Std. Cont. | 21,046 | SSC | 1959 | OKWSA (Gulf) |
| Caddo | Magnolia | No. 1 Troy Smith | 12-11N-11W | Std. Cont. | 15,503 | — | 1959 | Mobil |
| Carter | Frankfort | No. 1 Bohanan | 4- 5S - 3W | Std. Cont. | 8,235 | SSC | 1959 | OKWSA (Frankfort) |
| Comanche | Conoco | No. 1 Mansel | 14- 3N-10W | Std. Cont. | 9,502 | SRS | 1959 | Conoco |
| Custer | Gulf | No. 1 Burgtorf | 6-13N-15W | Std. Cont. | 13,565 | Century | 1959 | OKWSA (Gulf) |
| Hughes | Texaco | No. 1 Doern-McKenzie | 31- 6N-10E | Std. Cont. | 4,620 | SSC | 1959 | Texaco |
| Jackson | Atlantic | No. 1 Hulett | 5- 1N-23W | Std. Cont. | 7,421 | SSC | 1958 | Atlantic |
| Jefferson | Magnolia | No. 1 Gulf Fee | 22- 3S- 5W | Std. Cont. | 6,438 | Magnolia | 1959 | Magnolia |
| Major | Gulf | No. 1 H. C. Wichert | 14-21N-13W | Std. Cont. | 8,786 | SSC | 1959 | OKWSA (Gulf) |
| McClain | Texaco | No. 1 Ratliff | 24- 7N- 4W | Std. Cont. | 11,907 | SRS | 1959 | OKWSA (Texaco) |

| County | Company | Lease | Location | Type | Survey Depth | Shot by | Date | Sponsored by |
|---|---|---|---|---|---|---|---|---|
| Oklahoma | Renco & Vierson | No. 1 Beresford | 1-14N- 4W | Standard | 6,868 | SSC | 1945 | Phillips |
| Pittsburg | Warren Bradshaw | No. 1 Cole | 36- 8N-12E | Std. Cont. | 5,932 | Magnolia | 1959 | Magnolia |
| Roger Mills | Magnolia | No. 1 Fred L. Young | 3-15N-24W | Std. Cont. | 13,280 | — | 1959 | Magnolia |
| Stephens | Gulf | No. 1 Stella Jones | 14- 2N- 5W | Std. Cont. | 14,493 | SSC | 1959 | Gulf |
| Stephens | Conoco | No. 9 Martin "C" | 12- 2S - 4W | Intg. Sonic | 7,500 | PGAC | 1960 | Conoco |
| Stephens | Conoco | No. 1 Cooper | 11- 2N- 9W | Std. Cont. | 10,190 | SRS | 1960 | OKWSA (Conoco) |
| Texas | Phillips | No. 2 Muss | 16- 1N-14E | Std. Cont. | 8,390 | SRS | 1959 | Phillips |
| Texas | Texaco | No. 1 State Lands "W" | 35- 5N-10E | Std. Sonic | 4,865 | — | 1959 | Texaco |
| Woodward | Gulf | No. 1 M. F. Ward | 14-24N-20W | Std. Cont. | 7,615 | Century | 1959 | Gulf |
| | | | STATE OF TEXAS | | | | | |
| Andrews | Ralph Lowe | No. A-1 Morgan | Sec. 11, Blk. A50, PSL | Std. Cont. | 11,492 | Magnolia | 1959 | Magnolia |
| Andrews | Shell | No. 1 Brown | Sec. 20, Blk. A-41, PSL | Std. Cont. | 12,020 | PGAC | 1960 | Shell |
| Andrews | Humble | State University "BO" | Sec. 6, Blk. 6, Univ. Lands | Std. Cont. | 12,679 | SRS | 1959 | Humble |
| Bailey | Phillips | No. 1 Stephens | Sec. 24, Blk."B," M. Bum & Blum | Standard | 8,223 | SGC | 1951 | Phillips |
| Bandera | Shell | La Casse No. 1 | Sec. 17, J. J. Brady Survey | Std. Cont. | 10,010 | PGAC | 1960 | Shell |
| Bordon | Texaco | No. 1 Johnson | Sec. 38, Blk. 31, T 5N | Std. Cont. | 9,173 | SRS | 1959 | Texaco |
| Brazoria | Pan American | No. 1 Moore Unit | HT & B Survey, A-482 | Std. Cont. | 9,414 | SSC | 1957 | PanAm |
| Brazoria | Sunray | No. 1 R. D. McDonald | S. Old Ocean Field | Std. Cont. | 13,134 | SSC | 1959 | Sunray |
| Brazoria | Sunray | No. 1 Houston Farms, Inc. | Chocolate Bayou Field | Std. Cont. | 11,863 | Birdwell | 1959 | Sunray |
| Cass | Texaco | No. 1 Thompson | B. M. Dorris Survey | Std. Cont. | 11,946 | SRS | 1959 | Texaco |
| Cochran | Sunray | No. 1 C. R. Starnes | Sec. 25, Harrison & Brown Survey | Sonic | 12,170 | SRS | 1959 | Sunray |
| Cochran | Shell | Tanner & Enoch No. 1 | Lbr. 6, Lge. 139, Hemphell CSL | Std. Cont. | 7,744 | Empire | 1960 | Shell |
| Cochran | Shell | W. L. Harris No. 1 | Lbr. 23, Lge. 139, Hemphell CSL | Std. Cont. | 6,570 | PGAC | 1960 | Shell |
| Collingsworth | Nesbitt | No. 1 Tarpley | Sec. 65, Blk. 15, H & GN RR | Std. Cont. | 6,466 | Empire | 1959 | Shell |
| Crane | Humble | No. 1 A. R. Eppenauer | Sec. 23, Blk. 6, H & TC RR | Std. Cont. | 6,179 | SRS | 1959 | Humble |
| Crockett | Pan American | No. 1 Univ. "DL" | Sec. 31, Univ. Blk. 7 | Std. Cont. | 9,588 | SSC | 1959 | Sunray |
| Crockett | Monterey Oil | No. 23-40 Harris | Sec. 40, B.1, GC&SF RR | Std. Cont. | 8,050 | SRS | 1959 | Shell |
| Culberson | TXL | TXL No. 1 Harry Goode | Sec. 34, Blk. 60, T5, T&P | Std. Cont. | 10,172 | SRS | 1959 | SSWSA (TXL) |
| DeWitt | Shell | No. 1 Wm. M. Carroll | C. P. Delmas Survey A-157 | Std. Cont. | 18,000 | PGAC | 1959 | SSWSA (Shell) |
| Fisher | G. H. Stoddard | No. 1 Williams | Sec. 61, Blk. 2, H & TC | Std. Cont. | 6,935 | SRS | 1959 | Sunray |
| Foard | Shell | No. 1 H. Allison | Sec. 392, Blk. A, H & TC | Std. Cont. | 6,648 | SRS | 1959 | Shell |
| Gaines | Texaco | No. 1 Nelson | Sec. 256, Blk. G. WT RR | Std. Cont. | 11,938 | SRS | 1959 | Texaco |
| Gaines | Texaco | No. 1 Jones | Sec. 12, Blk. A-7, PSL | Std. Cont. | 11,111 | SRS | 1959 | Texaco |
| Gaines | Conoco | No. 17 Wasson 48 | Sec. 48, Blk. AX, PSL | Std. Cont. | 11,551 | SRS | 1960 | Conoco |
| Gaines | Humble | No. 1-C Argo Oil Corp. | Lge. 299, Lab. 9, Terry Co. SL | Std. Cont. | 12,823 | SRS | 1960 | Humble |
| Glasscock | TXL & U. S. Smelting | No. 1 TXL "41" | Sec. 41, Blk. 34, T3S, T&P | Std. Cont. | 10,773 | SRS | 1959 | TXL |
| Glasscock | Shell | No. 1 Alma Weyman | Sec. 14, Blk. 36, T3S, T&P RR | Std. Cont. | 11,476 | SRS | 1959 | Shell |
| Gonzales | Hunt Oil Co. | No. 1 Emil W. Stoeltje | R. H. Wynn Survey A-474 | Std. Cont. | 12,500 | — | 1960 | Hunt |
| Gray | Phillips | No. 1 Hobart | Sec. 26, I & GN | Std. Cont. | 9,893 | SSC | 1951 | Phillips |
| Gray | Clark | No. 1 D. I. Burnette | Sec. 143, Blk. 3, I & GN Survey | Std. Cont. | 7,572 | — | 1959 | Gulf |
| Grayson | Grande Corp. | No. 1 Harshbarger | Rueben Alexander Survey | Std. Cont. | 11,436 | — | 1959 | Mobil |
| Hansford | Phillips | No. 2 Hitch "E" | Sec. 10, Blk. 1, PSL | Std. Cont. | 8,485 | SRS | 1958 | Phillips |
| Hardin | SOG-Atlantic-McGill | Fee No. 4 | McGill Lge. A-38 | Std. Cont. | 13,000 | — | 1959 | Atlantic |
| Hidalgo | Dunlap Oil | No. 1 Bart Aldridge | Sec. 8, Lge. 3, Hidalgo CSL | Std. Cont. | 9,032 | Empire | 1959 | Sunray |
| Hockley | Texaco | No. 1 Wells | Sec. 112, Blk. A, R. M. Thompson | Std. Cont. | 11,248 | SRS | 1959 | Texaco |
| Hunt | Sunray | No. 1 J. W. Barrow | Lucius B. Polk Survey | Std. Cont. | 9,924 | SRS | 1960 | — |
| Jefferson | Texaco | No. 1 State Tract 80 | State Tract 80 (Gulf of Mexico) | Standard | 6,559 | Texaco | 1958 | Texaco |
| Jefferson | Pan American | No. 1 M. McFaddin Ward | Wm. McFaddin Survey, A-416 | Std. Cont. | 11,380 | Empire | 1958 | PanAm |
| Jefferson | Pan American | No. 1 W. G. Burrell | J. J. French Survey, A-23 | Std. Cont. | 10,599 | Empire | 1958 | PanAm |
| Jefferson | Pan American | No. 2 H. W. Gilbert | W. Kyle Survey, A-413 | Std. Cont. | 10,800 | Empire | 1958 | PanAm |
| Jefferson | Pan American | No. 1 F. Hebert | Burns & Caswell Survey, A-394 | Std. Cont. | 11,067 | Schlum. Reynolds | 1959 | PanAm |
| La Salle | G. L. Brown | No. 1 H. D. Storey | I & GN, A-390 | Std. Cont. | 10,414 | Empire | 1958 | PanAm |
| Lavaca | Mobil | No. 1 S. W. Kahanek | James Kerr Survey, A-24 | Std. Cont. | 14,358 | — | 1959 | Mobil |
| Live Oak | Tidewater-Shell | No. 1 Holman Cartwright | Francisco Botello Survey, A-80 | Std. Cont. | 15,997 | Empire | 1960 | SSWSA (Tidewater) |

| County | Company | Lease | Location | Type | Survey Depth | Shot by | Date | Sponsored by |
|---|---|---|---|---|---|---|---|---|
| Lynn | Shell | Coleman, et al. No. 1 | Sec. 1, Blk. L, GWT&P | Std. Cont. | 9,713 | PGAC | 1960 | Shell |
| Morris | Halbonty | No. 1 Joe Justiss | Nelson Survey, A-216 | Std. Cont. | 12,817 | Magnolia | 1960 | Mobil |
| Oldham | Atlantic | No. 1-84 Fulton Ranch | Sec. 84, Fulton Ranch Subd. | Std. Cont. | 7,952 | Empire | 1959 | Shell |
| Oldham | Shell-Atlantic | No. 1 Fulton Ranch "51" | Sec. 51, Fulton Ranch Subd. | Std. Cont. | 6,840 | PGAC | 1960 | Shell |
| Pecos | Phillips | Harral "A" No. 1 | Sec. 6, Blk. 126, T&STL | Std. Cont. | 17,994 | SSC | 1957 | Phillips |
| Pecos | Phillips-Sinclair | No. 1 Montgomery | Sec. 17, Blk. 134, T&STL | Std. Cont. | 23,000 | SSC | 1957 | Phillips |
| Pecos | Phillips | No. 1 Univ. "EE" | Sec. 7, Blk. 24, UL | Std. Cont. | 25,183 | SSC | 1957 | Phillips |
| Pecos | Atlantic | No. 1 J. W. Robbins | Sec. 2, N. A. Zinn Survey | Std. Cont. | 8,734 | SRS | 1959 | Atlantic |
| Pecos | Atlantic | No. 1 J. C. Kelly | Sec. 8, Blk. 51, T10, T&PRR | Std. Cont. | 19,062 | SRS | 1960 | Atlantic |
| Pecos | Humble | No. 1 Charles C. Cannon | Sec. 54, Blk. A-2, TCRR | Std. Cont. | 11,310 | SRS | 1960 | Humble |
| Potter | L. T. Bivins | Pedrosa No. 1 | Sec. 3. Blk. 4, ACH & B | Std. Cont. | 4,509 | PGAC | 1960 | Shell |
| Potter | Shell | Bivens Ranch No. 1-207 | Sec. 207, Blk. 2, AB&M | Std. Cont. | 6,378 | PGAC | 1960 | Shell |
| Red River | Magnolia | No. 1 L. C. Cooper | H. P. Benningfield Survey | Std. Cont. | 6,081 | Magnolia | 1959 | Magnolia |
| Reeves | Conoco | No. 1 Charlotte Montgomery | R. E. Montgomery State (A-538) Survey | Std. Cont. | 13,101 | SRS | 1959 | Conoco |
| Reeves | TXL | No. 1 Reeves "K-T" Fee | Sec. 35, Blk. 58, T7, T&P RR Survey | Std. Cont. | 9,709 | SRS | 1959 | SSWSA (TXL |
| Reeves | Keljikan | No. 1 Yadon | Sec. 238, Blk. 13, H & GN | Standard | 4,980 | Empire | 1958 | Atlantic |
| Schleicher | Atlantic | No. 1 W. H. Williams | Subd. "D," Sec. 42, H. E. & WT | Std. Cont. | 7,775 | Empire | 1959 | Atlantic |
| Shackelford | Magnolia | No. 1 J. H. Nail, Jr. Trustee | Sec. 550, TE & L Survey | Std. Cont. | 4,733 | Magnolia | 1959 | Magnolia |
| Sutton | Union Oil Co. | No. 1 Aldwell Brothers | 1320' FN&E Lines, Shirley Goodwin Sur. | Std. Cont. | 10,033 | Empire | 1959 | Union |
| Sutton | Texaco | No. 1-C Allison | Sec. 61, Blk. K, GH & SA | Std. Cont. | 6,390 | SRS | 1959 | Texaco |
| Terrell | Magnolia | No. 1 State-Brown | Sec. 32, Blk. 161, GC & SF | Std. Cont. | 12,603 | Magnolia | 1959 | Magnolia |
| Terrell | Great Western-Blue Dan-ube & B. Harwit | No. 1 Chapman | Sec. 64, B.Y., TCRR | Std. Cont. | 12,176 | — | 1959 | SSWSA (Phillips) |
| Terrell | Shell-Humble | No. 1 L. C. Smith | Sec. 5, Blk. A-2, TC&RR | Std. Cont. | 10,291 | SRS | 1959 | Shell |
| Terrell | Humble | No. 1 Annie Spencer | Sec. 68, Blk. B-2, CCSD & RGNG | Std. Cont. | 14,611 | SRS | 1960 | Humble |
| Upton | Shell | King Ranch Oil & Lignite Co. No. D-1 | Sec. 26, Blk. 2, MKT | Std. Cont. | 11,790 | Empire | 1960 | Shell |
| Upton | Penrose-Shell | Shirk Est. No. 1 | Sec. 25, Blk. 2, MKT | Std. Cont. | 10,395 | Empire | 1960 | Shell |
| Ward | Mobil | No. 1 George Sealy "56" | Sec. 56, Blk. "F" G & MMB&A | Std. Cont. | 16,288 | — | 1959 | Mobil |
| Ward | Humble | No. 43 Yarbrough & Allen | Sec. 66, E. J. Bradley Survey | Std. Cont. | 9,742 | SRS | 1959 | Humble |
| Webb | Pan American | No. 1 J. N. Garner | S. W. Wolcott, A-1948 | Std. Cont. | 10,475 | Empire | 1958 | PanAm |
| Webb | Hunt Oil Co. | No. 1 J. O. Walker | 18S-8E, Bell Jeffers Survey A-476 | Std. Cont. | 18,560 | — | 1960 | Hunt |
| Winkler | Humble | No. 1 Tennie Cowden | Sec. 24, Blk. A-55, PSL | Std. Cont. | 12,881 | SRS | 1960 | Humble |
| Wise | Tom Medders | No. 1 E. B. Clark | Abel Hodges Survey, A-370 | Std. Cont. | 8,420 | SSC | 1954 | Phillips |
| | | | STATE OF UTAH | | | | | |
| Carbon | Shell | North Springs Unit No. 1 | 27-15S - 9E | Std. Cont. | 12,675 | SSC | 1958 | Shell |
| Carbon | Shell | Farnham Dome Deep Unit No. 1-A | 8-15S -12E | Std. Cont. | 9,160 | Empire | 1959 | Shell |
| Duchesne | Standard of Calif. | No. 1 Rock Creek Unit 34-19A | 19- 2S - 5W | Std. Cont. | 10,109 | Birdwell | 1959 | RMSWSA (SOC) |
| Emery | Shell | Chaffin Unit No. 1 | 21-23S -15E | Std. Cont. | 7,702 | Empire | 1959 | RMSWSA (Shell) |
| Emery | Forest Oil Corp. | No. 25-1 Arnold | 25-16S -14E | Std. Cont. | 11,000 | Birdwell | 1959 | RMSWSA (Forest) |
| Emery | Texaco | No. 1 Temple Springs | 14-25S -13E | Std. Cont. | 7,309 | SRS | 1960 | Texaco |
| Grand | Murphy Corp. | No. 1 Little Valley | 29-26S -20E | Std. Cont. | 8,450 | Century | 1960 | RMSWSA (Humble) |
| Kane | J. R. McDermott | No. 1 State | 2-43S - 8W | Std. Cont. | 8,500 | — | 1959 | RMSWSA (Carter) |
| Millard | Shell | Baker Creek No. 1 | 19-20S -19W | Standard | 4,210 | Shell | 1956 | Shell |
| San Juan | Texaco | No. 2-W Navajo | 10-41S -24E | Std. Cont. | 5,600 | SSC | 1958 | Texaco |
| San Juan | Carter | No. 1 Gov't Hancock | 26-39S -17E | Cont. L. I. | 3,800 | — | 1959 | RMSWSA (Carter) |
| San Juan | Carter | No. 1 Rustler's Dome | 4-29N-20E | Std. Cont. | 5,400 | — | 1959 | RMSWSA (Carter) |
| San Juan | Pure | No. 1 N. W. Lisbon | 10-30S -24E | Std. Cont. | 8,434 | Century | 1959 | Pure |
| San Juan | Texaco | No. 1 Lasrich | 25-38S -21E | Std. Cont. | 6,570 | SRS | 1959 | Texaco |
| San Juan | Sinclair | No. 1 Federal Grand Gulch | 15-39S -16E | Std. Cont. | 3,401 | SRS | 1959 | Texaco |
| San Juan | Texaco | No. "P" 22 Navajo | 34-40S -25E | Std. Cont. | 5,886 | SRS | 1959 | Texaco |
| San Juan | Texas Pacific | No. 1 Navajo Tribal "B" | 28-32N-17W | Std. Cont. | 9,460 | Century | 1960 | RMSWSA (TPC&O) |
| San Juan | E. B. LaRue, Jr. | No. 1 Putnam (Moab Anticline) | 15-27S -22E | Std. Cont. | 8,058 | SRS | 1960 | RMSWSA (Conoco) |
| Wayne | Paradox Production | P. P. No. 1 Federal | 34-30S -13E | Std. Cont. | 6,290 | SSC | 1957 | Shell |
| Wayne | Murphy Corporation | No. 4 Nequoia | 14-28S -14E | Standard | 6,770 | SRS | 1959 | RMSWSA (Carter) |

| County | Company | Lease | Location | Type | Survey Depth | Shot by | Date | Sponsored by |
|---|---|---|---|---|---|---|---|---|
| Wayne | American Metal Climax, Inc. | No. 1 Moroni Slopes | 13-27S - 8E | Std. Cont. | 6,231 | SRS | 1959 | RMSWSA (Shell) |
| Wayne | Texaco | No. 1 Thousand Lakes, Mtn. Unit | 11-28S - 4E | Std. Cont. | 6,900 | SRS | 1959 | Texaco |
| | | | STATE OF WYOMING | | | | | |
| Campbell | Calco | Gov't Davis | 30-49N- 75W | Std. Cont. | 6,935 | SSC | 1957 | RMSWSA (Calco) |
| Campbell | Davis Oil | No. 1 Federal-Rogers | 28-58N- 71W | Std. Cont. | 7,579 | SSC | 1959 | RMSWSA (PanAm) |
| Campbell | Pan American | USA John Fallwell, Jr. No. 1 | 24-55N- 70W | Std. Cont. | 7,475 | SRS | 1959 | RMSWSA (PanAm) |
| Campbell | Sinclair | No. 1 Paluski Estate | 33-50N- 70W | Std. Cont. | 9,180 | SSC | 1959 | RMSWSA (Sinclair) |
| Campbell | Petroleum Inc. | Government-Sohio No. 1 | 11-56N- 69W | Std. Cont. | 5,682 | Birdwell | 1960 | RMSWSA (Conoco) |
| Campbell | Champlin | No. A-1 Government | 17-46N- 69W | Std. Cont. | 9,103 | SRS | 1959 | Champlin |
| Campbell | Conoco | No. 13-1 Harris-Simpson | 13-51N- 69W | Std. Cont. | 7,856 | Birdwell | 1960 | RMSWSA (Conoco) |
| Campbell | Davis Oil Co. | No. 1 State Potter | 16-50N- 71W | Std. Cont. | 9,699 | Birdwell | 1960 | RMSWSA (Gulf) |
| Campbell | Calco | No. 2 Cooper Reservoir Unit | 34-36N- 87W | Std. Cont. | 7,500 | Birdwell | 1959 | RMSWSA (Calco) |
| Campbell | Trigood | No. 1 Munoz Gov't | 19-51N- 70W | Std. Cont. | 9,009 | SRS | 1960 | RMSWSA (Gulf) |
| Carbon | Sohio | No. 1 Cow Creek Unit | 12-16N- 92W | Std. Cont. | 11,266 | SSC | 1959 | RMSWSA (Sohio) |
| Carbon | Sun | No. 1 Browning Gov't | 11- 4N- 91W | Std. Cont. | 9,719 | Birdwell | 1960 | RMSWSA (Sun) |
| Converse | Signal Drilling | No. 1 Unit (Dull Center Area) | 5-40N- 68W | Std. Cont. | 11,034 | Birdwell | 1960 | RMSWSA (Calco) |
| Crook | Davis Oil | No. 1 Federal Blatt | 35-54N- 68W | Std. Cont. | 6,577 | SRS | 1960 | RMSWSA (PanAm) |
| Crook | Texaco | No. 1 Jessen | 20-50N- 68W | Std. Cont. | 7,990 | SRS | 1959 | Texaco |
| Fremont | Conoco | No. 1 Moneta Hills | 11-27N- 91W | Std. Cont. | 9,545 | SSC | 1959 | RMSWSA (Conoco) |
| Fremont | Calco, et al. | No. 1 Frank E. Reynolds | 10-38N- 93W | Std. Cont. | 5,988 | SSC | 1959 | RMSWSA (Shell) |
| Fremont | Superior Oil | No. 1-26 Fuller Reservoir Unit | 26-36N- 94W | Std. Cont. | 9,142 | SSC | 1959 | RMSWSA (Superior) |
| Fremont | Gulf | No. 1 Lysite Federal | 23-39N- 91W | Std. Cont. | 6,774 | SSC | 1959 | RMSWSA (Shell) |
| Fremont | Carter | No. 1 Gov't Walker | 33-37N- 92W | Std. Cont. | 7,213 | SSC | 1959 | RMSWSA (Carter) |
| Fremont | Carter | No. 1 Gov't Vinson | 13-33N- 91W | Std. Cont. | 6,000 | Birdwell | 1959 | RMSWSA (Carter) |
| Fremont | Conoco | Squaw Butte Unit 1-2 | 1-36N- 90W | Std. Cont. | 8,650 | Birdwell | 1960 | RMSWSA (Conoco) |
| Fremont | Shell | No. 23-15 Howard Ranch | 15-39N- 93W | Std. Cont. | 11,474 | SRS | 1960 | RMSWSA (Shell) |
| Johnson | C. F. Raymond | No. 1 Government | 32-44N- 81W | Std. Cont. | 7,285 | Birdwell | 1960 | RMSWSA (PanAm) |
| Lincoln | Conoco | No. 1 Dry Hollow | 24-25N-114W | Std. Cont. | 7,698 | SSC | 1959 | RMSWSA (Conoco) |
| Lincoln | Conoco | No. 23-1 Hams Fork Unit | 23-20N-116W | Std. Cont. | 5,986 | SSC | 1959 | RMSWSA (Conoco) |
| Natrona | Calco | No. 1 Waltman Unit | 31-37N- 86W | Std. Cont. | 11,892 | SSC | 1959 | RMSWSA (Calco) |
| Natrona | Calco | No. 2 Cooper Reservoir Unit | 34-36N- 87W | Std. Cont. | 8,619 | SSC | 1959 | RMSWSA (Calco) |
| Natrona | Davis Oil | No. 1 Mohawk-Monterey | 22-34N- 88W | Std. Cont. | 6,000 | SRS | 1959 | RMSWSA (Mobil) |
| Natrona | Pure | No. 2 Badwater Unit | 2-38N- 89W | Std. Cont. | 9,786 | SRS | 1960 | RMSWSA (Pure) |
| Natrona | True Oil Co. | No. 1 Sun Ranch Unit | 30-34N- 85W | Std. Cont. | 9,015 | Birdwell | 1960 | RMSWSA (Humble) |
| Natrona | Calco | No. 2 Waltman Unit | 1-36N- 87W | Std. Cont. | 7,500 | SSC | 1959 | RMSWSA (Calco) |
| Natrona | Conoco | Squaw Butte Unit 23 No. 3 | 23-36N- 89W | Std. Cont. | 8,258 | Birdwell | 1960 | RMSWSA (Conoco) |
| Niobrara | Ohio Oil Co. | No. 1 Gov't Great Basins | 1-38N- 66W | Std. Cont. | 8,314 | SSC | 1959 | RMSWSA (Ohio) |
| Niobrara | Pure | No. 2-A Badwater Unit | 2-38N- 89W | Std. Cont. | 16,493 | SRS | 1960 | RMSWSA (Pure) |
| Niobrara | Conoco | No. 1 Buck Creek Unit | 18-36N- 63W | Std. Cont. | 6,422 | SSC | 1958 | Conoco |
| Sheridan | Trigood | No. 2 Ingram | 3-54N- 77W | Std. Cont. | 10,265 | SSC | 1959 | Sunray |
| Sublette | Gulf | New Fork Lake Unit—Federal No. 1 | 5-36N-110W | Std. Cont. | 6,761 | SSC | 1959 | RMSWSA (Gulf) |
| Sublette | El Paso Natural Gas Co. | No. 7 Pinedale Unit | 15-30N-108W | Std. Cont. | 10,255 | SRS | 1960 | RMSWSA (Conoco) |
| Sweetwater | Calco | No. 2 Monument Butte | 22-26N-110W | Std. Cont. | 8,015 | SRS | 1959 | Calco |
| Sweetwater | Belco Petr. Corp. | No. 1 Eden Unit | 17-22N-106W | Std. Cont. | 10,827 | SSC | 1959 | RMSWSA (Gulf) |
| Sweetwater | John L. Kemmerer | No. 1 Laney Rim Unit | 20-18N- 97W | Std. Cont. | 9,000 | Birdwell | 1959 | RMSWSA (El Paso) |
| Sweetwater | Caulkins | No. 4-9V Currant Creek | 9-14N-106W | Std. Cont. | 7,303 | SSC | 1959 | Calco |
| Sweetwater | Phillips | No. 1 Cedar Mountain Unit | 28-15N-111W | Std. Cont. | 10,999 | SSC | 1959 | RMSWSA (PanAm) |
| Sweetwater | Pan American | No. 1 Henry's Fork Unit | 10-12N-110W | Std. Cont. | 7,500 | Birdwell | 1960 | RMSWSA (PanAm) |
| | | | CANADA | | | | | |
| Alberta | Atlantic, et al. | Marlboro 6-16 | Twp 55, R 18, W 5th | Std. Cont. | 12,230 | SSC | 1959 | Atlantic |

# REVISIONS AND CORRECTIONS

(Corrections are in italics)

| *County* | *Company* | *Lease* | *Location* | *Type* | *Survey Depth* | *Shot by* | *Date* | *Sponsored by* |
|---|---|---|---|---|---|---|---|---|
| | | | **NEVADA** | | | | | |
| Eureka | Shell | Diamond Valley No. 1 | 30-23N-54E | Standard | 8,034 | Shell | 1957 | *Shell* |
| | | | **NORTH DAKOTA** | | | | | |
| Golden Valley | Shell | No. N. P. *41-35* | 35-139N-103W | Std. Cont. | 9,100 | SSC | 1958 | RMSWSA (Shell) |
| Oliver | Carter | Semling No. 1 | 19-141N- 81W | Standard | 8,310 | Texas | *1942* | Carter |
| | | | **WYOMING** | | | | | |
| Fremont | Calco | No. 1 Spratt | 5-38N-90W | *Cont.* | 8,980 | SSC | 1957 | RMSWSA (Calco) |
| Fremont | SunRay-MidCont. | No. 1-A Federal | *32*-39N-91W | Std. Cont. | 4,690 | SSC | — | RMSWSA (*Shell*) |

# DEPARTMENTS

## PATENTS

O. F. RITZMANN†

### MAGNETIC PROSPECTING

*U. S. No. 2,938,164.* M. Hansburg. Iss. 5/24/60. App. 6/25/57. Assign. U.S.A.

*Automatic Earth Field Balance Control System for Magnetometers.* A system for cancelling the ambient field affecting a magnetic detector in which the detector output is filtered by a low-pass filter and fed to an amplifier with degenerative feedback from the detector, so that signals passing through the filter are suppressed and only higher frequency anomalies are indicated.

*U. S. No. 2,942,177.* J. Neumann, H. Weiss, and F. Assmus. Iss. 6/21/60. App. 5/6/55 and 5/1/56. Assign. Siemens-Schuckertwerke Aktiengesellschaft.

*Method and Means for Measuring Magnetic Field Strength.* A device for measuring ferromagnetic properties of material by placing a wafer of semiconductor material with high carrier mobility edgewise against the material to be tested and observing the change in transverse electrical resistance of the wafer or its Hall-effect voltage.

*U. S. No. 2,942,179.* F. B. Coker. Iss. 6/21/60. App. 11/12/53. Assign. United Geophysical Corp.

*Magnetometer Circuit.* A magnetometer having a flux-gate element with compensating winding that is connected in series with a resistor in a feedback loop arranged to compensate the field to which the element is exposed, the voltage across the resistor being measured by a self-balancing potentiometer-recorder.

*U. S. No. 2,942,180.* F. B. Coker. Iss. 6/21/60. App. 11/12/53. Assign. United Geophysical Corp.

*Magnetic Field Measuring System.* A magnetometer having a pair of flux-gate elements in an unbalanced bridge circuit whose output produces positive and negative pulses that are amplified and the difference in amplitudes between successive pulses of opposite polarity indicated.

### RADIOACTIVITY PROSPECTING

*U. S. No. 2,935,614.* C. F. Teichmann and C. G. Ludeman. Iss. 5/3/60. App. 5/17/54. Assign. Texaco Development Corp.

*Radioactive Prospecting.* An airborne radioactivity surveying system in which a camera periodically photographs the terrain and a radioactivity detector collimated to receive radiation from the same area is connected to a counting rate meter and amplifier to make a visual record of observed radioactivity on the same or on a correlated film.

*U. S. No. 2,939,010.* S. A. Scherbatskoy. Iss. 5/31/60. App. 12/23/53.

*Directional Radiation Detector.* A directional detector for hard gamma rays having three scintillating crystals in line each with a photomultiplier tube connected to a triple coincidence circuit.

### SEISMIC PROSPECTING

*U. S. No. 2,935,697.* L. B. McManis. Iss. 5/3/60. App. 7/18/57. Assign. Pan American Petroleum Corp.

*Seismic Amplifier Gain Control.* A seismograph avc system in which the output of the seismic

† Gulf Oil Corporation, Patent Department.

channel is amplified, rectified, and used to control diode bridge attenuators in two preceding stages of the channel, the degree of attenuation for the early stage of the channel being higher than for a later stage.

*U. S. No. 2,935,723.* W. J. Stark and R. L. Wilcox. Iss. 5/3/60. App. 11/9/56. Assign. Jersey Production Research Co.

*Multiple Geophone Connector.* An electrical connector having an insulated support with a number of polarized and interconnected terminal posts to which geophone wires and jumper cable can be connected.

*U. S. No. 2,935,728.* A. R. Morgan. Iss. 5/3/60. App. 2/15/46. Assign. Radio Corp. of America.

*Underwater Object Locator.* A directional object locator having a piezoelectric transducer excited with frequency modulated radio frequency pulses and the frequency of the reflection compared with that of the source.

*U. S. No. 2,937,915.* R. A. Peterson. Iss. 5/24/60. App. 12/19/55. Assign. United Geophysical Corp.

*Recording System.* A channelized galvanometric recording system in which each trace is optically repeated by light spots of lower intensity on each side of the main oscillograph beam, so that when the main beam exceeds the boundary of the channel at high amplitude the repeat traces still show the signal within the channel.

*U. S. No. 2,938,195.* S. J. Begun, G. P. Chan, and A. P. Dank. Iss. 5/24/60. App. 7/8/54. Assign. Clevite Corp.

*Multichannel Magnetic Recording.* A system for changing the time phase between the tracks of a multichannel magnetic record by re-recording the record with the tracks on separate drums that are adjustably mounted on a common shaft so that the time phase of the drums can be changed on playback.

*U. S. No. 2,938,592.* C. J. Charske and C. L. Hubbard. Iss. 5/31/60. App. 3/23/53. Assign. Jersey Production Research Co.

*Seismic Velocity Well Logging Apparatus.* An acoustic well logging system having a source and two detectors embedded in a rubber sonde, the source being energized by a condenser at relatively long intervals and the difference in arrival time at the two detectors converted to a d-c signal that is recorded at the surface.

*U. S. No. 2,938,670.* V. W. Bolie. Iss. 5/31/60. App. 2/28/57. Assign. Collins Radio Co.

*Means for Measuring Correlation.* A correlation computer in which the two functions are applied to parallel resistors in series with an output resistor whose power is measured by a heat detector that controls a power source whose output is indicated.

*U. S. No. 2,939,079.* P. L. Willmore. Iss. 5/31/60. App. 10/21/57. Assign. Canada.

*Method of Calibrating an Electromagnetic Seismograph.* A system for calibrating a seismometer by connecting it in one arm of a bridge circuit and connecting the seismometer galvanometer as the bridge-balance detector, balancing the bridge with the seismometer coil clamped, and then observing the galvanometer deflection with a-c of various frequencies applied to the bridge when the seismometer is unclamped.

*U. S. No. 2,939,107.* J. D. Ball. Iss. 5/31/60. App. 7/1/57. Assign. Jersey Production Research Co.

*Recordation of Seismic Signals.* A calibrated reflection seismograph ave system in which the shot energy is determined by a rectifying and integrating circuit whose input is cut off after the first arrivals and whose output is applied to a potentiometer that controls the seismograph amplification, the potentiometer being mechanically varied with time by a connection to the recording drum.

*U. S. No. 2,940,061.* R. G. Piety. Iss. 6/7/60. App. 10/24/55. Assign. Phillips Petroleum Co.

*Signal Recording System.* A seismic recording system in which the signals are amplified and differentiated and the amplified signal applied to positive and negative gate circuits that are controlled by the differentiated signal, the outputs of the two gate circuits being separately recorded.

*U. S. No. 2,940,062.* J. P. Lindsey. Iss. 6/7/60. App. 2/6/56. Assign. Phillips Petroleum Co.

*Tuning System.* A seismograph filter system having a noise rejector circuit that rejects damped wave trains and followed by a tuning network that is sensitive to waves having the form of the second derivative of the normal density function.

*U. S. No. 2,940,536.* C. B. Bazzoni, L. G. Ellis, and A. C. Winterhalter. Iss. 6/14/60. App. 3/2/53. Assign. Sun Oil Co.

*Method and Apparatus for Anaysis of Seismic Records.* An apparatus for producing a corrected record from a magnetic seismogram in a re-recording process in which the pick-up heads are adjusted so as to provide fixed corrections and also moved to correct for normal stepout and for stepout due to a dipping reflecting bed.

*U. S. No. 2,941,184.* H. H. Moody. Iss. 6/14/60. App. 4/27/56. Assign. Continental Oil Co.

*Method for Plotting Seismic Data.* A method of automatically transferring seismic data from a seismogram to a time or depth section in which the traces are scanned in pairs and each time a predetermined condition of amplitude or slope reversal is simultaneously recognized on both traces a pulse is generated that is plotted on a synchronized tape.

*U. S. No. 2,941,615.* T. H. Holmes. Iss. 6/21/60. App. 5/1/56. Assign. Texaco Inc.

*Device for Loading Tandem Charge Arrays.* An anchoring device for the bottom of a shot hole having a hollow cylindrical container with outwardly flaring prongs that engage the wall of the hole and with a smaller transversely mounted cylinder around which a firing line with spaced charges can be threaded so as to permit adjustment of the charges to the desired depths.

*U. S. No. 2,942,195.* W. C. Dean. Iss. 6/21/60. App. 5/15/58. Assign. Gulf Research & Development Co.

*Electrical Filter Circuits.* Seismograph filter circuits made up of extended ladder sections with a running ground and with each section having a response of the Laguerre type, the outputs from a number of sections being combined to provide a readily computable overall transient response characteristic.

*U. S. No. 2,942,462.* H. M. Buck. Iss. 6/28/60. App. 6/5/57. Assign. Jersey Production Research Co

*Device for Measurement of Pressure or Temperature in Wells.* A go-devil for recording a characteristic of well fluid in a flowing well having a sensing device recording on a drum that is advanced stepwise each time a finger detects a tubing joint when the device is dropped in a well and finally releases an annular flexible packer so that the flow of well fluid will propel the device back up to the surface.

*U. S. No. 2,942,782.* R. B. Blizard, R. Proskauer, and V. Vacquier. Iss. 6/28/60. App. 6/11/54 and 1/26/55. Assign. Sperry Rand Corp.

*Sonar Ray Tracer.* An analog computer for computing a family of ray paths of sound in a medium from measured values of sound velocity as a function of depth which is entered into a cathode ray-phototube type of function generator, the computed ray paths being displayed on a c-r tube screen.

*U. S. No. 2,943,258.* E. N. Shawhan. Iss. 6/28/60. App. 8/12/54. Assign. Sun Oil Co.

*Apparatus for Impedance Measurements.* An impedance measuring circuit for use with a capaci-

tance transducer having a long connecting cable and in which the exciting oscillator is switched at a low frequency between the transducing capacitor and a series-connected reference capacitor and the difference between the two parts of the cycle detected.

*U. S. No. 2,943,268.* C. Dodge. Iss. 6/28/60. App. 7/30/57. Assign. Texaco Inc.

*Automatic Gain Control Amplifier Circuit.* A seismograph avc system having two feedback loops each with a pair of silicon diodes and a resistor in a voltage divider circuit and each loop having a rectifier and filter whose output is used to control the impedance of the diodes.

WELL LOGGING

*U. S. No. 2,934,947.* H. M. Buck. Iss. 5/3/60. App. 8/8/55. Assign. Jersey Production Research Co.

*Flowmeter.* A well flowmeter having a rotor on a vertical shaft with flow deflectors above and below the rotor to direct the flow against the rotor blades and with the shaft carrying a coded contactor that completes a circuit to the surface.

*U. S. No. 2,934,955.* P. H. Monaghan. Iss. 5/3/60. App. 7/22/57. Assign. Jersey Production Research. Co.

*Apparatus for Measuring Temperatures.* A borehole temperature indicator having a number of vials of insulating material with contacts at their upper ends and a solid insulating meltable material of high density at the top of the vial and a conducting liquid of low density at the bottom of the vial so that when the heavier material melts the lighter liquid will close an indicating circuit to the surface.

*U. S. No. 2,935,615.* M. E. True. Iss. 5/3/60. App. 6/24/57. Assign. Jersey Production Research Co.

*Well Logging Tool Fluid Displacer.* A radioactivity logging tool in which the measuring apparatus is inside an expansible packer that is inflated by gas pressure under control of a four-way solenoid valve actuated from the surface.

*U. S. No. 2,935,871.* R. G. Pearson. Iss. 5/10/60. App. 4/10/56. Assign. Geolograph Service Corp.

*Well Logging Apparatus.* A drilling rate recorder having two recording drums one of which records traveling block movements when not drilling and the other records progress of drilling and is disengaged for other operations.

*U. S. No. 2,936,375.* A. S. McKay. Iss. 5/10/60. App. 12/27/55. Assign. Texaco Inc.

*Radioactivity Bore Hole Logging.* A neutron-gamma-ray well logging system in which a caliper log of the hole is simultaneously made with the voltage from the caliper tool effecting the recording of a reference curve for a borehole of the observed diameter to calibrate the gamma-ray curve.

*U. S. No. 2,937,278.* G. V. Copland. Iss. 5/17/60. App. 3/20/57. Assign. Welex, Inc.

*Directional Scintillation Well Logging Apparatus.* A radioactivity detector having an axial scintillating crystal and phototube with the upper portion of the axial crystal surrounded by a scintillating crystal and the lower portion of the axial crystal surrounded by another crystal with phototube, the phototubes being connected to an anti-coincidence circuit so as to record only horizontally directed radiation.

*U. S. No. 2,937,333.* E. Boucherot. Iss. 5/17/60. App. 12/26/56 and 12/23/57. Assign. Societe de Prospection Electrique Procedes Schlumberger.

*Bore Hole Telemetering Apparatus.* An electric logging signalling system in which a resistor equal to the load is connected to the conductors when the circuit is interrupted so as to eliminate transient effects.

*U. S. No. 2,937,527.* D. F. Mason, G. Thodos, and L. F. Stutzman. Iss. 5/24/60. App. 4/9/56. Assign. Strike Investment Co.

*Apparatus for Determining the Production Potential of Wells.* A system for transmitting bottom-hole pressure or temperature to the surface by having the transducer move a Selsyn generator connected by a cable to a repeater at the top of the well.

*U. S. No. 2,938,117.* K. H. Schmidt. Iss. 5/24/60. App. 3/23/56. Assign. Petroleum Service and Research Corp.

*Analysis Determinative of Gas or Oil Producing Strata.* A system of mud logging in which gas is extracted from the circulating mud stream and passed through a multicomponent infrared absorption analyzer and the concentration of components separately recorded.

*U. S. No. 2,938,708.* J. J. Arps. Iss. 5/31/60. App. 9/19/57.

*Simultaneous Drilling and Electrical Logging of Hydrocarbon Contents of Formations.* A system of electric logging while drilling in which the self-potential of formations is measured by means of electrodes on an insulated drill collar and the salinity of the drilling mud adjusted to be the same as that of the fluid in the formation being drilled.

*U. S. No. 2,940,177.* J. M. Bricaud. Iss. 6/14/60. App. 2/2/56. Assign. Schlumberger Well Surveying Corp.

*Apparatus for Exploring Bore Holes.* A well surveying apparatus having a pool of conducting liquid in an insulated container with electrodes in its outer wall and also having a suspended magnet, the electrodes being scanned by a motor-driven contactor and the resistance measured and the azimuth of the magnet determined by a coil driven by the same motor.

*U. S. No. 2,940,370.* J. L. Yandell. Iss. 6/14/60. App. 12/11/58.

*Bottom Hole Camera.* A photographic device run on the end of well tubing and having a tank with lights and camera on its lower end and having by-pass valves so that clear water may be discharged from the tank for taking a picture or the tank by-passed for raising and lowering the device in the well.

*U. S. No. 2,941,405.* P. F. Southwick. Iss. 6/21/60. App. 4/10/56. Assign. Gulf Research & Development Co.

*Mud Sampler and Pressure Indicator.* A device for obtaining well fluid samples at known depth having a series of chambers each having a seal that is broken at a known pressure to allow fluid to enter the chamber and a float valve that closes the chamber when full, the frangible seals of the successive containers being connected in an electric circuit that signals the operation to the operator by a change of resistance.

*U. S. No. 2,941,784.* J. L. Martin. Iss. 6/21/60. App. 7/5/55. Assign. The Atlantic Refining Co.

*Logging While Drilling.* A system of electric logging while drilling using insulated sections in the drill string and a down-hole recorder connected to metallic sections.

*U. S. No. 2,942,111.* A. E. Worthington. Iss. 6/21/60. App. 6/28/55. Assign. California Research Corp.

*Contoured Logging Sonde.* A gamma-gamma density logging sonde in which both the incident and the scattered beams are collimated and the sonde has protuberances at the collimating openings so as to insure that these openings are always in contact with the borehole wall even though the latter may be rough and irregular.

*U. S. No. 2,942,112.* D. P. Hearn. Iss. 6/21/60. App. 12/28/56. Assign. Well Surveys, Inc.

*Multiple Well Logging System.* A system for transmitting a number of signals over a single conductor by means of a modulated carrier on which is superimposed positive and negative pulses, the signals being represented by the modulation, the positive spikes, and the negative spikes.

*U. S. No. 2,942,461.* E. R. Filley. Iss. 6/28/60. App. 12/16/55. Assign. Texaco Inc.

*Well Bore Hole Logging.* A thermostated boot for calibrating a radioactivity logging device, the boot being heated either electrically or by circulating engine exhaust gas.

*U. S. No. 2,943,197.* L. de Witte. Iss. 6/28/60. App. 10/14/54. Assign. Continental Oil Co.

*Method of Well Logging.* A method of analyzing well fluid to locate points of entry of salt water by directing a stream of neutrons along the axis of the well and detecting only gamma rays of a particular energy due to neutron capture by chlorine or sodium.

*U. S. No. 2,943,200.* J. A. Rickard. Iss. 6/28/60. App. 10/19/56. Assign. Jersey Production Research Co.

*Stable Isotope Method for Well Logging.* A radioactivity logging method using a neutron source and gamma-ray detector that is connected to a pulse-height discriminator that selects pulses indicative of neutron capture by two isotopes of carbon or sulphur and recording the ratio of their counting rates to determine the isotopic ratio.

MISCELLANEOUS

*U. S. No. 2,940,039.* L. Yost, W. R. Wilson, and R. A. McCreary. Iss. 6/7/60. App. 6/10/57. Assign. one-half to A. O. Smith Corp. and one-half to California Research Corp.

*Well Bore Electricel Generator.* A tachometer generator for a turbine drill having an annular permanent magnet rotor on an extension of the turbine shaft and a sealed stator whose winding is connected to the drill pipe and to an insulated electrode, the a-c signal being picked up at the surface from connections to the drill pipe and a spaced ground electrode and its frequency indicated.

*U. S. No. 2,942,176.* E. R. Brownscombe and E. M. Connell, Jr. Iss. 6/21/60. App. 5/7/57. Assign. The Atlantic Refining Co.

*Method and Apparatus for Determining Characteristics of Earth Formations.* An apparatus for determining the formation factor of a parallel-sided rock sample in which the sample is placed between the ends of two coaxial capillary tubes filled with the rock-saturating liquid and the electrical resistance across the sample is measured.

*U. S. No. 2,943,319.* W. R. Hunsicker. Iss. 6/28/60. App. 5/3/55. Assign. Seismograph Service Corp.

*Radio Location System.* A continuous-wave phase-comparison type of radio location system in which the fixed stations use the same radiating antenna for both coarse and fine position indicating signals.

*U. S. No. 2,943,320.* J. E. Hawkins. Iss. 6/28/60. App. 10/4/55. Assign. Seismograph Service Corp.

*Radio Location System.* A continuous-wave phase-comparison type radio location system in which three fixed stations radiate signals of different frequencies and the signals are heterodyned in pairs and the beat frequency used to modulate the third signal from which one side band of the modulation is eliminated.

*U. S. No. 2,943,321.* M. A. Karpeles. Iss. 6/28/60. App. 1/6/58. Assign. International Telephone and Telegraph Corp.

*Course Guidance System.* A radio navigation computer in which polar coordinate position information and wind direction and velocity information obtained from a TACAN radio beacon is converted to a null-type indication to guide the pilot along a preset straight line course.

SELECTED LIST OF U. S. PATENTS

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* A key to the subject classification system will be found in GEOPHYSICS, v. 12, pp. 256–264 (April, 1947).

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Reviews of *Resistivity Determinations from Electric Logs* and *Electric Analogue for Resistivity Logging* by Hubert Guyod, and of *Analysis Charts for the Determination of True Resistivity from Electric Logs* by Hubert Guyod and John A. Pranglin, appeared in the June issue, pages 701 and 702. Objection to the opinions expressed in these reviews was received from the principal author, Dr. Guyod, and others. Independent reviews were accordingly invited by the Editor from Mr. G. E. Archie, the Associate Editor for WELL LOGGING. These reviews are presented herewith.

*Analysis Charts for the Determination of True Resistivity from Electric Logs*, Hubert Guyod and John A. Pranglin, Hubert Guyod, Houston, 1959, 202 pp., $22.50.
*Resistivity Determinations from Electric Logs*, Hubert Guyod, Hubert Guyod, 1957, $20.00.

These manuals give a wealth of information on estimating the true formation resistivity from electric logs comprising normal resistivity, lateral resistivity, and SP curves which record only apparent resistivity data. The electrical resistivity of a rock is a function of its porosity, fluid saturation

and other factors. In order to determine rock characteristics in this manner, therefore, one must be able to determine the true resistivity. The manuals do not explain how to estimate the reservoir characteristics once the true resistivity is known.

The first book presents a method for determining the true resistivity and the extent of the invaded zone from the 16-inch and 64-inch normals, and the 18-foot 8-inch lateral curves. The method is applicable when $R_i$ (invaded zone resistivity) is greater or smaller than $R_t$ (true formation resistivity). An analogue computer was used to obtain most of the data. The book contains over 250 charts that permit determining $R_t$ and, in many cases, $R_i$ and $D_i$ (depth of filtrated invasion) for single isotropic beds from two to 50 feet thick, and for comprehensive ranges of resistivities "$R_i$," "$R_t$," "$R_s$" (shale resistivity), and $R_m$ (mud resistivity) hole sizes and invasion diameters. Instructions are given for the application of data to certain nonuniform formations. A discussion of the resolving power of resistivity curves and of the effects of inaccuracies in the various pertinent factors $R_a$, $R_m$, $R_s$, $e$ (thickness), $d$ (borehole diameter) is presented.

The second book was originally prepared as a field manual for six major oil companies. This manual gives the background necessary for the practical use of resistivity curves and the field data for determining the resistivity of single beds and of multiple-layer formations.

The two books should, therefore, be used together. Typical logs are given for single formations, multiple- and sandwich-type formations. Familiarity with typical characteristic shapes of various resistivity curves as recorded through layers of these geometries is important for interpretation.

The large number of variables encountered in attempting to arrive at the true resistivity of a layer makes it necessary for the specialist to have a full understanding of a range of simple cases to more complicated ones, as well as being fully aware of inaccuracies. Therefore, these manuals provide excellent background for the specialist who wants to take the time necessary to find the best estimate of the true resistivity of a layer in order to approach in-situ reservoir conditions. Although normal and lateral resistivity logs are being replaced by focused resistivity logs, older well logs recorded on nearly all wells since the 1930's will be more important in the United States in the future because of the emphasis on secondary recovery.

G. E. ARCHIE
Shell Development Company
Houston, Texas

*Electric Analogue for Resistivity Logging*, Hubert Guyod, Hubert Guyod, Houston, 1958, 137 pp., $50.00.

This book summarizes work done with an analogue computer for six major oil companies. Calculated data for resistivity well logging utilize the relationship between apparent resistivities, $R_a$, true resistivities, $R_t$, and other pertinent factors. It is generally impossible to state this relationship as an explicit expression giving true resistivity. Therefore, the usual method for determining the resistivity of beds from electric logs is to establish charts relating $R_a$ and $R_t$ and to use these charts to analyze the field data. In the past these charts were generally obtained by calculations, using a method which has the disadvantage that it is very time-consuming.

The report comprises two parts: The first part describes at length the construction of the analogue and its operations; well bore and rock formations were simulated by electrical resistances. The second part is a thorough summary investigation of the response of normal and lateral resistivity curves on single and multiple beds. It discusses the apparent resistivity, shapes of curves, and methods of analysis.

This book is not necessary for the field man; however, it should be extremely useful in research departments, universities and log analysts' libraries, and valuable to anyone who may be confronted with similar problems that may be solved on an analogue computer. The principle, construction, and operation are discussed in detail.

G. E. ARCHIE
Shell Development Company
Houston, Texas

High-Frequency Filtering as a Means of Eliminating Multiple Reflections, A. M. Epinat'eva and L. A. Ivanova, *Bulletin (Izvestiya), Academy of Sciences, USSR, Geophysics Series*, No. 3, March 1959, pp. 244–252, translated and published by The American Geophysical Union, May 1960.

The two Russians who collaborated on this experiment set out to design a seismic system that would provide better discrimination against certain multiple reflections than the conventional systems previously used. Their success with a high-frequency system (peak = 105 cps) is worthy of note. In this reviewer's opinion, however, they may be seriously in error in attributing their success entirely to the frequency response of the system used.

The authors chose to conduct the majority of their experiments in an area where the basement depth is only 1600 to 1700 meters, excellent for high-frequency techniques. Four geophones per group spaced five meters apart along the profile were used in the high-frequency system, whereas the conventional medium frequency system (30 to 50 cps) utilized only one geophone per group. Recordings at long ranges (up to 1000 meters) were made, and the normal moveout observed on these long range records was used as the basis for distinguishing interbed multiple reflections from primary reflections. At the high frequencies used, the geophone groups will be especially effective in discriminating against the higher normal moveout of the interbed multiples. No such discrimination would be obtained from the single geophone used in the medium frequency system. (The geologic section is conformable with a dip of less than one degree, so dip moveout is very small.) Thus, the dimensions of the geophone groups may be as important a factor in their successful system as the frequency response.

Obviously, very shallow reflections at long ranges would have the greatest normal moveout so would be most heavily attenuated by the geophone groups. This problem was neatly sidestepped by arbitrarily ignoring all events occurring earlier than a "reference reflection" at a depth of 750 to 850 meters.

In justification of using geophone groups, the following statement appears: "Grouping of geophones increased the intensity of the recordings 3 to 4 times. The trace appeared also more regular than with single geophones, and no addition or loss of waves occurred." (???)

It should be pointed out that the simple multiple of the "reference reflection" was neatly eliminated by the high-frequency system. Examination of the records presented appears to indicate that the geophone group dimensions are not a contributing factor.

This article, incidentally, is quite difficult to read because the translator obviously is not well acquainted with seismological terms.

THOMAS L. SLAVEN
Western Geophysical Company of America
Los Angeles, California

Electric Prospecting by the Telluric Currents Method, A. M. Zagarmistr and M. N. Berdichevskiy, *Petroleum Geology*, Vol. 3, No. 1-B, 1959 (English edition published June 1960), pp. 40–49.

The English edition of the original Russian paper is clearly written and informative. It is divided into three parts, (1) introduction section covering the general aspects of the telluric-current method together with its relation with other geophysical methods, (2) regional telluric-current investigations of reconnaissance nature in the poorly studied Kanta-Mansiysik depression of the western part of West Siberian Lowland, and (3) telluric-current exploration of local geologic structures within larger geological structural units.

Russian interest in the telluric-current method of prospecting for oil and gas is made evident by the revelation that 111,200 sq km of Russia were covered by this exploration method during the three-year period, 1955–1957 inclusive.

Very few details of the method as used in Russia are reviewed; however, a concise and informative general statement of the cosmic origin of telluric currents and the required technique of simultaneous measurements of two orthogonal components of the telluric field at two distant (10 km) points is given

The second part of the paper deals with the initial geophysical reconnaissance coverage of wide areas of unknown regional and local geology. A specific telluric-current survey of the northern part of

the Shatilkov depression is briefly reviewed. It is pointed out that subsequent seismic work conducted in the same area has confirmed the information derived from the method of telluric currents.

The third part of the paper reviews exploration work by the telluric-current method, within a small-scale portion of the Shatilkov depression. It is pointed out that the local structures were studied by merely increasing the density of the network of telluric-current observations.

Several interesting sketch maps and data profiles, combining geological data with results obtained by the telluric method, are presented. The agreement between the telluric-current method measurements and geological information is emphasized. It is reported that the method gave good geological results in a majority of the cases. Apparently the method was less effective in areas where thick cemented deposits outcrop.

The conclusion of the paper is that the use of the telluric-current method of exploration will or has become an integral part of the regional geophysical investigations of the broad areas in Siberia and Central Asia.

This paper is of value to the geophysicist interested in the possibilities and limitations of the telluric-current method of exploration.

Joshua L. Soske
Stanford University
Stanford, California

On the Application of Cagniard's Method to Dynamical Problems of Elasticity, M. Mitra, *Gerlands Beiträge Zur Geophysik*, Vol. 69, No. 2, pp. 73–86, 1960.

The paper by M. Mitra uses first the Laplace transform with respect to the time, then the Fourier transform with respect to the horizontal distance, and then finally the Laplace transform again with respect to the vertical distance or the distance perpendicular to the interface, thus reducing the problem he considers to an algebraic one. The paper is an interesting variation of Cagniard's method applied to the problem of reflection and refraction of two-dimensional seismic pulses.

C. Hewitt Dix
California Institute of Technology
Pasadena, California

*Space Technology*, edited by Howard S. Seifert, John Wiley & Sons, Inc., New York, 1959, 1172 pp., $22.50.

This remarkably excellent volume is based on a series of postgraduate lectures in space technology offered by the Extension Division of the Department of Engineering and Physical Sciences of the University of California. It is interesting to note that in spite of the highly analytical nature of this course, over four thousand students (including this reviewer) registered for this series at the various branches of the University. In his preface to the book, Dr. Seifert states: "That such an intense interest was shown in the subject was not unrelated to the fact that Sputnik I was launched a few months before the course began."

The subject of space technology is discussed in five broad categories, subdivided into thirty-three chapters and written by thirty-eight authors, each of whom has gained recognition in the field of his specialty. The five categories discussed are as follows:

*Flight Dynamics:* This section of eleven chapters is largely a space-age adaptation of the classical disciplines of analytical dynamics and celestial mechanics. After introducing the fundamental concepts and definitions suitable for the proper parametrization of rocket flights, the authors treat the theory and the problems of optimization of terrestrial, satellite, lunar, and interplanetary trajectories. Some attention is given to the common fallacy of the simple balancing of Newtonian fields and this leads quite naturally to a discussion of the velocity contours based on the very important Jacobi's integral for the restricted three-body problem. Looking into a somewhat more distant future, a full chapter is devoted to the well-known relativistic time dilatation effect, leading to the inescapable conclusion that for sufficiently high velocities of travel, astronauts will indeed age more slowly than those who have remained "at home." This section closes with a discussion of the thermal problem of re-

entry into the atmosphere as well as the more general problem of achieving nondestructive landing on a given planet.

*Propulsion and Structures:* The seven chapters of this section unfold an exciting drama of man's ingenuity (though, as yet, no final solution) in the face of natural physical laws which are ostensibly unsympathetic with his cosmic goals.

A designer would like the terminal velocity of his rocket to be as high as possible and at the same time to retain a large fraction of the original mass. An elementary consideration, however, of the conservation of momentum between the rocket and its exhaust, leads to the following fundamental equation of rocketry with which he must contend, namely, Terminal Velocity = Exhaust Velocity $\times \log_e$ (Mass Ratio), the last being the ratio of the initial total mass to the final total mass. Obviously, then, beyond a certain point a small increase in the terminal velocity has to be paid for by a terrible sacrifice in the final mass, which of course includes the payload. This impasse leads the designer to consider the remaining parameter, viz., exhaust velocity. Here, more sophisticated considerations of momentum and adiabatic expansion of gases lead to a very cumbersome equation which, in part, states that the exhaust velocity is proportional to $\sqrt{T/M}$, where $T$ is the combustion temperature (°K) and $M$ is the mean molecular weight of the exhaust gases. Now, then, if one can supply heat by means other than chemical, one can also use substances of low molecular weight such as hydrogen or helium, and thus gain a substantial overall advantage. While this opens new and unlimited vistas of approach, it also unfolds a myriad of unsolved problems and engineering difficulties. Dr. Seifert summarizes this whole situation in the following classic statement: "Since an effective rocket should spend mass frugally, it must squander energy prodigally."

The topics in this section include the following: fundamentals of nozzle flow and optimum nozzle geometry (which is by no means self-evident); liquid, solid, nuclear, and thermonuclear rocket propulsion (with an excellent chapter on the fundamentals of magnetohydrodynamics); analysis of structural problems; and, finally, application of the systems approach to the integrated design.

*Communication, Guidance, and Control:* A variety of topics is covered in the six chapters of this section. Weight limitations place an upper bound on the permissible transmitter power in the spacecraft. On the other hand, because distances may well get very large and in view of the inverse square law, the inherent noise of the receiver is an immediate problem, and sets the lower bound on the usability of a given transmitted signal. This problem is treated within the framework of information theory which is very briefly sketched. Next, the theory, advantages, and disadvantages of the following modes of guidance are discussed: radio guidance, inertial guidance, radio-inertial guidance, and the new subject of midcourse and terminal guidance. An interesting subsection treats the topic of smoothing a stationary time series in the context of guidance problems.

*Man in Space:* This phase of space technology is perhaps more familiar to general readers because of the numerous articles which have appeared in national magazines. The four chapters of this section analyze man in terms of his psychological and physical responses to weightlessness, confinement, stress, radiations, and accelerations. The section includes a chapter on the design of space cabins.

*Applications of Space Technology:* Two chapters discuss the use of satellites for research in space physics, some aspects of special instrumentation, and a brief sketch of methods of data handling. The third chapter is a panel discussion: What the Future Holds.

This reviewer has been asked on several occasions why the name of von Braun was not included among the authors of the book. Dr. von Braun was, in fact, one of the invited speakers. However, instead of appearing in person, as all the other busy lecturers have done, he chose rather to send a "warmed over" film version of his "Exploration of Mars," with himself as the narrator. A fair portion of the audience considered this an affront, as was evidenced by vociferous sounds of disapproval. The editor is to be commended for excluding this material from his book for, in this reviewer's opinion, it lacked the two most important qualities present in all the other lectures: freshness and sophistication.

It is warmly suggested that all earth-men whose thoughts are not earth-bound ought to have a copy of this unique and excellent volume on their reference shelves.

MARK HOLZMAN
Western Geophysical Company of America
Los Angeles, California

*Nomography*, A. S. Levens, John Wiley & Sons, Inc., New York, 1959 (Second Edition), viii+296 pp., $8.50.

To those who have used the first edition (1948) no words of introduction are needed. Improved in format, revised and expanded by about 90 percent, and including three new chapters on circular nomograms, projective transformations, and the relationship between concurrency and alignment nomograms, the new edition is an up-to-date treatment of a subject which is continually enlarging its field of application.

A comparison with the first edition shows that although the basic structure is unchanged, additions have been made to almost every chapter. Noteworthy features of the new edition include the application of nomographic methods to test the validity of experimental data curves, an expanded treatment of the "method of determinants," a simple approach to projective transformations, and the Duality Principle ("for every line of the concurrency nomogram there is a corresponding point in the alignment nomogram") and its application to the transformation of families of experimental data curves from concurrency to alignment charts. The Appendix which previously contained twenty-nine nomograms has been doubled and covers applications to engineering, statistics, physics, food technology, medicine, etc.

The book can serve admirably both as a text and as a reference.

H. KAUFMAN
McGill University
Montreal, Canada

*Modern Probability Theory and Its Applications*, E. Parzen, John Wiley & Sons, Inc., New York, 1960, xv+464 pp., $10.75.

Despite the increasing importance of the theory of probability to the physical, social and engineering sciences, there has been a dearth of texts combining a mathematically sound treatment with well-chosen technical applications. One of the best to date has been Feller's *Introduction to Probability and Its Applications*. Parzen's book is a worthy addition to the growing list of acceptable volumes.

The first six chapters constitute a course in elementary probability theory. Beginning with the notions of "event," "sample description space," and the basic definition of probability as a function of events on a sample description space, the author carefully proceeds to develop the concepts of independence and dependence, numerical-valued random phenomena, mean and variance of a probability law, and the normal, Poisson and other distributions. The theory is profusely illustrated with well-chosen examples. The unhurried development is attested by the fact that not until chapter 7 is the concept of "random variable" introduced.

The final two chapters are of a considerably more advanced nature, providing careful and rigorous derivations of the law of large numbers and the central limit theorem. A valuable feature is the inclusion of sets of exercises, theoretical and nontheoretical (numerical) at the end of each section.

Those of us who have been confronted with the rudimentary type of text on the one hand, and the formidable treatises of Doob and Loève on the other, will be amply rewarded by a thorough study of this book.

H. KAUFMAN
McGill University
Montreal, Canada

*An Outline of Geomorphology*, S. W. Wooldridge and R. S. Morgan, Longmans, Green, and Co., Ltd., London, 1959, xix+409 pp., 32 shillings.

This is the eleventh edition of a book first published in 1937. It is designed as a textbook for advanced geography students, and its purpose is to describe topography in terms of geological processes. The illustrations, 271 in number, plus the wealth of material within its 23 chapters, make this book most interesting reading. It is probably of considerable value to those who are encountering geology for the first time and to whom geology as such is of secondary importance. To geologists and geo-

physicists, many imperfections should be apparent. The original title was "The Physical Basis of Geography, An Outline of Geomorphology." It is unfortunate that the authors reversed it, as it places an improper emphasis on the book as a text on geomorphology.

A statement on the cover says that ". . . the bibliography has been thoroughly revised to include the most recent papers and texts." Perhaps so, but the text itself does not show evidence of much revision. In more than a dozen places, it is apparent that recent work has been overlooked. An example of this ". . . recently there have been significant developments in geophysical prospecting, involving the use of detailed torsion balance surveys. . . ." Furthermore, in an eleven-page discussion of the controversial subject of continental drift, there is no mention of evidence of drift and polar wandering from paleomagnetic measurements.

The first ten chapters deal with the geological basis or background for the remaining 13 chapters which pertain to the configuration of the earth's surface. Subject matter includes "The Origin of the Earth," "Isostasy," "Mountain Building," "Origin of the Forces Responsible for Earth Movement," "The Cycle of Erosion," "Denudation Chronology," "Marine Erosion and Shore-Lines," and "Glacial Control in the Physical Geography of the Earth." The phrases in quotations are the titles of eight of the chapters.

It is the reviewer's opinion that this book, with weaknesses as described above, is a valuable addition to the library.

JAMES AFFLECK
Gulf Research & Development Company
Pittsburgh, Pennsylvania

*The Geological Evolution of North America*, T. H. Clark and C. W. Stearn, The Ronald Press Company, New York, 1960. vi+434 pp., $7.50.

The authors have done an excellent job of presenting a logically developed, smooth reading introduction to historical geology. The book reads more like a novel than a text book. There are no references in the text itself though selected references are listed at the end of each chapter.

"The historical development of the continent is present in terms of its three major structural units: the bordering geosynclines, the stable interior, and the Canadian Shield. A greater unity of treatment is, we believe, achieved by considering the development of these great structural units throughout geologic time, or through a major part of it."

The introductory chapter discusses geologic time and illustrates the principles involved in lithologic and paleontological correlation. Theories regarding the origin of the earth and the solar system are briefly reviewed.

As much of historical geology is the story of sedimentation and tectonics of geosynclines, the authors provide a simplified explanation of the geosynclinal theory. They define a geosyncline as "an elongated belt in the earth's crust that is subsiding currently or that has subsided for long periods in the past so that it acts, or has acted, as a trap or collecting basin for sediments removed by erosion from uplifted areas of the crust. Axial zones of maximum subsidence receive great thicknesses of sediments until they become unstable and the belt is then crushed by folding and elevated into a mountain chain."

After describing the geologic history of the stable interior (including the origin of such famous oil-producing formations as the St. Peter, Oriskany, Chester, Mission Canyon, and the Silurian and Devonian reefs), the history and evolution of the marginal geosynclines—the Appalachian and Cordilleran—are presented in considerable detail. The stratigraphy, lithology, and structural evolution of these marginal geosynclines are traced from the Precambrian to the Recent.

These chapters are followed by an up-to-date review of the geology of the Arctic Islands. The complex geologic history of the Canadian Shield, or the continental nucleus, and its role in the growth of the North American Continent are discussed. The final topic of this section of the book is The History of the Great Ice Age.

The last four chapters concern the evolution of life on earth as shown by the fossil record. An appendix contains a short summary of the Plant and Animal Kingdoms.

The book is profusely illustrated with photographs and simplified diagrams which are extremely effective. In describing the history of the more important formations, the authors point out which ones are major hydrocarbon producers.

C. E. WEAVER
Continental Oil Company
Ponca City, Oklahoma

New Methods of Elevation Control Speed Reconnaissance Gravity Surveys in Northern Areas, Norman R. Paterson, *The Canadian Mining and Metallurgical Bulletin*, Vol. 53, No. 580, pp. 614–622, August 1960.

The paper gives a quantitative comparison of three methods of gravity surveying which do not require running levels between stations. The comparisons were undertaken to evaluate the methods which might be used in areas such as northern Canada where ground transportation is very difficult and where reconnaissance gravity surveys with lower accuracy than is obtained with usual field procedures could give useful results. Transportation by helicopter can carry gravity meters readily to station locations under such conditions but if instrumental surveying for horizontal control and ordinary spirit leveling are used to determine positions and elevations the economy of helicopter transportation is largely lost. The paper, therefore, is concerned with methods of operation in which locations are determined from aerial photographs or maps and elevations by other means than spirit leveling or are avoided.

Elevations can be determined by photogrammetric methods with the elevations along the line of flight controlled by the Airborne Profile Recorder (APR) which is a precise radar altimeter with readings corrected by a hypsometer which determines variations from the normal pressure elevation. The paper discusses the types and magnitudes of errors which may be encountered. The example used covers an area of about 15 by 20 mi. northeast of Toronto with local relief of approximately 500 ft. The photography was at a height of 20,000 ft and scale 1:40,000 with the photogrammetric determinations made in a Wild Model A7 stereo-triangulation instrument. The results were compared with spirit level elevations at the same points. A histogram of the error distribution shows that 77 percent of the elevations had errors of less than 5 ft and 5 percent had errors greater than 10 ft.

A test over the same area was made with barometric altimeters. The various methods of altimeter operation are discussed. The test was made using the altimeter in much the same way as the gravity meter, i.e., by assuming a linear pressure change between base readings and without using recording barographs. The author concluded that most of the errors are due to uncompensated instrument drift and hysteresis and to local pressure changes due to wind velocity. The instrumental errors (drift and hysteresis) possibly would have been reduced materially by carrying several altimeters and averaging the results. The histogram of the errors shows that 65 percent are better than 5 ft and 11 percent are greater than 10 ft, with a mean square error of 5.6.

A test of a "gravity gradient" system carried out by the Robert H. Ray Company is included. This system depends on a triangle of three accurate gravity stations with distances of the order of 1,000 ft between stations and calculating the magnitude and direction of the average gravity gradient from the gravity differences and geometry of the three stations. A gravity map can be calculated by integrating the average gradient from these measurements in the same way that gravity maps are computed from torsion balance data. The only leveling required is that between the stations of each group and elevations from group-to-group are not needed. This system, therefore, could be used by selecting favorable local sites for each group and using helicopter transportation between these locations and no intermediate surveying would be required. A test of this system was carried out in Lee County, Texas and compared with gravity meter readings. On the basis of some 20 stations from 1 to 2 mi apart, the average differences between the gravity from gravity meter and from the integrated gradients was about 0.65 mg.

The paper concludes with a table summarizing the precision, rate of progress, and costs for various systems. Since this table is a good summary of the entire paper, it is reproduced here.

| Gravity Survey Specifications (station spacing in miles) | Elevation Control Method | Final Mean Accuracy (milligals) | Average Speed of Survey (square miles/day) | Approx. Final Cost for 2000–5000 Square Mile Survey (dollars/square mile) |
|---|---|---|---|---|
| ½×1 | Photo—transit | 0.05–0.10 | 10– 20 | 50–70 |
| 1×2 | Photo—transit | 0.05–0.10 | 15– 30 | 40–60 |
| 1×2 | Photogrammetry. Existing 1:60,000. Existing A.P.R. and ground control. | 0.50–1.00 | 80–100 | 10–15 |
| 1×2 | Photogrammetry. Existing 1:60,000. New A.P.R. | 0.30–0.50 | 80–100 | 20–30 |
| 1×2 | Photogrammetry. New 1:40,000 and A.P.R. | 0.20–0.30 | 80–100 | 30–40 |
| 1×2 | Altimeter. Base looping. | 0.50–1.00 | 80–100 | 8–12 |
| 1×2 | Altimeter. Base looping and base recording. | 0.40–0.80 | 60– 80 | 15–20 |
| 1×2 | Altimeter. Leap-frog and base recording. | 0.10–0.50 | 30– 50 | 30–50 |
| 1×2 | Horizontal Gravity Gradients. | 0.50–1.00 | 40– 50 | 20–30 |

L. L. NETTLETON
Gravity Meter Exploration Company
Houston, Texas

*Die Karte der mittleren Freiluftanomalien für Gradabteilungen 6′×10′ von Westdeutschland* (Map of Mean Free Air Anomalies for a 6′×10′ Coordinate Grid of West Germany), Karl Gerke and Heinz Watermann, Publication No. 32, Institute of Applied Geodesy, Frankfort, Germany, 1959, 18 pp.+map. (This is also Heft No. 46, Teil II of Reihe B, of the Deutsche Geodatische Kommission bei der Bayerischen Akademie der Wissenschaften.)

As the title indicates, the authors have calculated mean free-air gravity anomaly values in West Germany and environs in a grid of areas about 7×7 mi square. The values, which range from −52 to +94 milligals, are shown to the nearest milligal on a map of scale 1:1,000,000. The results are not contoured on the map but a color scale indicates areal ranges in values in 20-milligal steps.

A brief text (in German with summaries in German, English and French) describes the details of the calculation procedure and precision of the results. The English summary is especially comprehensive. References are given to source materials and related publications, mostly in German. There is no discussion of the geophysical applications of the results which presumably will follow in subsequent publications.

This paper is one of a series of gravity studies of central Europe by the Institute of Applied Geodesy in the German Geodetic Commission. A companion Bouguer anomaly gravity map was published in 1957. The associated map of average ground elevations, required in the calculations of the free-air anomalies, was published in 1959. (See accompanying review.)

The area reported covers all of central Europe from Belgium and the northeastern tip of France on the west, Poland on the east, Denmark and southern Sweden on the north, and small portions of northern Italy and Yugoslavia on the south. This series of publications furnishes very useful data for regional studies of isostasy, tectonics and structure in the area.

SIGMUND HAMMER
Gulf Research & Development Company
Pittsburgh, Pennsylvania

*Karte der mittleren Hohen von Zentraleuropa* (Map of Mean Elevations in Central Europe), Alfred Schleusener, Publication No. 31, Institute of Applied Geodesy, Frankfort, Germany, 1959, 8 pp. +map. (This is also Heft No. 60 of Reihe B, of the Deutsche Geodatische Kommission bei der Bayerischen Akademie der Wissenschaften.)

This paper consists essentially of a map showing average ground elevations in a grid of rectangular areas of about 125 square kilometers each. A brief text (in German, with summaries in English, French and German) describes the construction of the map and gives references to original sources. The map covers all of central Europe from Belgium and the northeastern tip of France on the west, Poland on the east, Denmark and southern Sweden on the north and small portions of northern Italy and Yugoslavia on the south.

The grid areas have been conveniently chosen to be nearly square (6 ft latitude $\times$10 ft longitude). The average elevations were computed from available topographic maps and represent the average topographic elevation in each grid area within an accuracy of $\pm 2$ to $\pm 10$ meters. In some of the bordering areas and especially in the high Alps the errors may be considerably larger. The grid elevations range from 0 to nearly 3,000 meters.

The map was constructed as a necessary computational step in preparing an average free-air gravity anomaly map of central Europe which has been published as a companion paper by Gerke and Watermann. (See accompanying review.) Its publication will facilitate gravitational studies of geodetic and regional tectonic problems in the area.

SIGMUND HAMMER
Gulf Research & Development Company
Pittsburgh, Pennsylvania

## PUBLICATIONS RECEIVED

### BOOKS

*Physics of the Upper Atmosphere*, edited by J. A. Ratcliffe, Academic Press, New York, $14.50.
*Soviet Research in Geophysics* v. 1, 2 & 3, American Geophysical Union, Washington, D. C., v. 1, $8.00, v. 2, $6.50, v. 3, $6.00.
*Crystal-Structure Analysis*, by Martin J. Buerger, John Wiley & Sons, Inc., New York, $18.50.
*Statistical Theory of Communication*, by Y. W. Lee, John Wiley & Sons, Inc., New York, $16.75.
*Lead Isotopes in Geology*, by R. D. Tussell and R. F. Farquhar, Interscience Publishers, New York, $9.00.

### PERIODICALS

*Annales de Geophysique*, v. 16, n. 2 (1960)
*Annali di Geofisica*, v. 13, n. 1 (Jan.–Mar., 1960)
*Boletin de la Asociacion Mexicana de Geologos Petroleros*, v. 12, nos. 1 & 2 (Jan. & Feb., 1960)
*Bulletin (Izvestiya)*, nos. 5–12 (May–Dec., 1959)
*Bulletin of the Research Council of Israel*, v. 9G, n. 1 (April, 1960)
*Bulletin of the Seismological Society of America*, v. 50, n. 2 (April, 1960)
*Chronique de l'U.G.G.I.*, n. 30 (May, 1960)
*Deutsche Hydrographische Zeitschrift*, v. 13, n. 1 (1960)
*Deutsches Hydrographisches Institut Jahresbericht*, n. 14 (1959)
*Economic Geology*, v. 55, n. 5 (August, 1960)
*Erdöl Und Kohle*, v. 13, nos. 6 & 7 (June & July, 1960)
*Geophysical Abstracts*, v. 180 (Jan. & March, 1960)
*Geophysical Prospecting*, v. 8, n. 2 (June, 1960)
*Gerlands Beitrage Zur Geophysik*, v. 69, n. 2 (1960)
*Journal of Earth Sciences Nagoya University*, v. 8, n. 1 (March, 1960)
*Journal of Geophysical Research*, v. 65, nos. 7 & 8 (July & August, 1960)
*Journal of Petroleum Technology*, v. 12, nos. 7 & 8 (July & August, 1960)
*Journal of Technology*, v. 4, n. 1 (June, 1959)
*Mining Engineering*, v. 12, nos. 7 & 8 (July & August, 1960)
*Mines Magazines*, v. L, nos. 5, 6, 7 & 8 (May–August, 1960)
*Physics Today*, v. 13, nos. 7 & 8 (July & August, 1960)
*Proceedings of the Cambridge Philosophical Society*, v. 56, n. 3 (July, 1960)
*Quarterly Journal of the Geological Society of London*, v. 116, n. 461, Part I (July, 1960)
*Rocznik*, v. 29, n. 4 (1959)
*Tellus*, v. 12, n. 2 (May, 1960)
*The Science Reports of the Tohoku University*, v. 11, Supplement (March, 1960)
*Transactions and Proceedings of the Geological Society of Africa*, v. 62 (1959)

## MEMORIALS

### JAMES LOUIS CATT

JAMES LOUIS CATT died suddenly of a heart attack on Easter Sunday, April 17, 1960, at his home in Tulsa, Oklahoma. Funeral services were held on April 19 and interment was at Lyons, Kansas. The news of his untimely death came as a shock to his family, his associates, and his many friends.

Jim, as he was better known, was born October 15, 1914, at Cashion, Oklahoma. His family later moved to Lyons, Kansas, where Jim attended Lyons High School, graduating in 1932. In 1935 he entered Sterling College at Sterling, Kansas. He graduated in 1939 with a Ph.B. in mathematics.

Jim started to work in the training program of Seismograph Service Corporation in January, 1941. In December, 1942, he entered the Army of the United States. He was assigned to the 654th Engineer Topographical Battalion where he eventually became First Sergeant of Co. A. He was discharged in December, 1945, and returned to Seismograph Service Corporation in January, 1946. He was made party chief in 1946. He worked in most of the oil provinces of the United States and also spent some time in Canada in 1948 and 1949.

Jim left Seismograph Service Corporation in 1955 to join the newly formed

Geo Prospectors, Inc., as a seismologist. He was elected to offices in Prospectors Drilling Corporation and Geo Exploration, Inc., by his associates. He held these positions until the time of his death.

Jim is survived by his wife, Viola, and by two daughters, Janet and Marla at home, by his sister, Miss Cora Catt, of Larned, Kansas, and by his mother, Mrs. Zett Catt, of Lyons, Kansas.

His passing is keenly felt by his many friends and associates. His friendliness, ability, and integrity will be an inspiration to all of us who knew and worked with him.

B. G. PRESTON

E. E. ROSAIRE

Esme Eugene Rosaire was born in Chicago, Illinois on June 17, 1897, to Claude and Julie (Carrol) Rosaire. After graduating from Tuley High School, he entered college at the University of Chicago, but his studies were interrupted by the war. In 1917 he enlisted in the Air Service, was commissioned a Second Lieutenant in 1918 and served in France with the 138th Aero-Squadron, Fifth Pursuit Group, until his discharge in 1919. He returned to college and received his Bachelor of Science degree in 1920; this was followed by the Master of Science

degree in 1921, and in 1926 the University of Chicago granted him the Doctor of Philosophy degree in Chemistry and Physics.

From 1923 until 1925, Gene was a physical chemist in the Development Branch of the Western Electric plant in Hawthorne, Illinois. His originality and inventiveness immediately became evident and was rewarded by the issuance of two U. S. patents.

Gene joined the Geophysical Research Corporation in 1925 and served as Field Superintendent until 1932. He was the first man in the field for the GRC, and in 1926 his refraction crew discovered the Moss Bluff salt dome in Liberty County, Texas, the first salt dome discovery made in this country by an American crew. Next, his crew discovered Port Barre and Bullard; later, Gene established a record of nine salt dome discoveries in twelve months.

After resigning from GRC in 1932, Gene assisted in the organization of Independent Exploration Company; he served as its president and general manager until 1937, when he severed his connection to organize Subterrex, the first American company to offer geochemical parties on a contract basis. From 1942 until his death he was a senior partner in Geochemical Surveys of Dallas, Texas.

The study of the strategy and tactics of war quickly gained Gene's interest and attention. He began with "On War" by von Clausewitz, "Napoleon" and "Great Captains" by Dodge, and Mahan's "The Influence of Sea Power upon History." Gradually, he acquired a large collection of books which covered the lives and campaigns of the great captains in detail. During the middle thirties, he began to recognize the similarities between the successful conduct of war and success in prospecting for petroleum; beginning with a paper in 1935, "On the Strategy and Tactics of Exploration for Petroleum," he delineated elements in exploration which were analogous to "Offense," "Defense," "Surprise," and "Economy of Force." The Second World War intensified his interest; following the third paper on strategy and tactics in 1939, he published "Prospecting Principles" for private distribution in 1940; in this paper he established exploration on a broad basis and exhibited striking parallelisms between various aspects of prospecting and the conduct of the initial campaigns of World War II.

A keen intellect coupled with high intelligence roams the field of knowledge and pauses here and there to cultivate small areas. Thus, in the early forties, Gene became interested in the study of society and devoted intensive attention to the works of Pareto, Michels, Mosca, Sorel, Spengler, Sorokin, Toynbee and Burnham. A paper on the application of the scientific method in the social field followed this study; calling attention to Pareto, he defined logical conduct as human action in which three components simultaneously apply: 1. The action is motivated by a deliberately held goal or purpose; 2. The goal is attainable; 3. The means or steps taken to reach the goal are appropriate to achieve that end. Numerous examples of non-logical conduct were given; Gene had an abundance of experience with scientists who were unable to apply the scientific method even in their chosen area of science, and he did not anticipate the early adoption of

the scientific method in the field of social activity, since the use of the scientific method would require discarding emotion in human conduct.

Gene believed that scientists and engineers should participate in civic affairs. Accordingly, he assumed civic responsibilities. He joined several young lawyers who had returned from the war, and the reorganized the Taxpayers Association of Houston into the Tax Research Association of Houston and Harris County.

During the late war years, Gene became active in the National Society of Professional Engineers and its state and local groups. He served as a national director for one year, in 1946, as a state director, and for several years he was active in the local San Jacinto Chapter as president, 1947–1948, and as program chairman. The TSPE awarded to Gene a certificate for outstanding service in 1958.

When the Engineers' Council of Houston was organized, Gene took an active part and became its vice-chairman in 1946–1947; he helped in writing its constitution and in the preparations for two symposia, one on atomic energy and the other on natural resources, which were addressed by illustrious speakers with national reputations. Finally, he was a director of the Houston Engineers Club and served as the editor of its monthly publication, *The Slide Rule*, during 1947–1948.

In Dallas, Gene was a member of the Northwood Country Club and of the Hillcrest Estates Association; he was president of the latter organization in 1949.

Early in the year 1930, Gene joined the late D. C. Barton and others in a drive to persuade the geophysisicsts residing in the Houston area to form an organization. After several luncheon meetings, the drive was successful and the Society of Petroleum Geophysicists was organized with Barton as President and Gene as Vice-President. The new Society became a technical division of the American Association of Petroleum Geologists in 1932; the AAPG had published the geophysical papers presented at the San Antonio meeting in March, 1931. The American Physical Society had published the geophysical papers offered at its meeting in New Orleans in December, 1931. Thereafter the AAPG published the papers presented at the meetings of the Society of Petroleum Geophysicists in its Bulletin as the Transactions of the Society. The last publication by the AAPG was Volume V, which appeared in March, 1935. The AAPG determined editorial policy and frowned upon the printing of highly technical and mathematical papers; however, the objections were usually removed by correspondence and meritorious papers were published.

The growth of the Society was slow; two years were required to double the membership. Then, the membership doubled in 1934 and trebled by March, 1937. The increase in 1934 was due largely, if not entirely, to Gene's efforts; he had been elected President in that year. Soon he recognized some impediments in the way of growth; he became convinced that the Society must become independent, must have its own publication, and that its activities must include

the instructors of the subject of geophysics in the institutions of learning and the mining geophysicists; in brief, the scope must embrace all geophysical activity and membership must be open to all qualified workers in geophysics in the broadest sense. At about this time, it was reported that the AAPG was considering an amendment to its constitution to provide that all members of technical divisions must be members of the AAPG, but it was never established which level of the AAPG did the considering, and no official communication on the subject was received.

More and more members of the Society adopted the viewpoint that the name must be changed, a new constitution must be written, and independence from the AAPG must be achieved. There were protests by AAPG members and predictions of dire consequences if the Society were to leave the fold; there were advices from Society members with geological background to leave well enough alone. The rebels prevailed; in 1936 the name was changed to The Society of Exploration Geophysics and, in 1937, the AAPG released the Society. The membership then increased spontaneously by leaps and bounds without any concerted effort on the part of the officers. For years upon years, the SEG and the AAPG held their annual meetings together, at the same time and place, and most cordial relations existed between them. As for Gene, his objective having been achieved, he never again made any effort to influence the operation or the policies of the SEG; its management and operation were taken over by devoted and competent younger men serving the Society. The success of the Society attests to the effectiveness of their efforts. In 1951, the Houston Geophysical Society elected Gene to honorary membership.

The Texas Acacemy of Science, the American Assocition for the Advancement of Science, and the Institute of Petroleum Technologists (British) elected Gene to fellowship. He was a member of the AAPG, the AIME, the American Geophysical Union, the American Society of Military Engineers, the U. S. Naval Institute, the Society of the Sigma Xi, the National Society of Professional Engineers, the Foreign Policy Association, and, of course, the SEG.

Gene first touched my life in 1929; during the ensuing years the acquaintanceship ripened into friendship. He had a pleasant, stimulating personality, versatility of interests, and a marked talent for analysis. "Let's take it apart and examine the pieces," he would say. Whatever captured his interest, he studied, organized, and mastered. An evening with him was always a stimulating experience. We could discuss and debate, agree and disagree, but our bonds of friendship were strengthened. After his removal to Dallas, we were forced to communicate by correspondence and this we did, at least once each month.

Gene married Johnie Laureme Ransone on June 24, 1928. His widow, daughter Carol Jean (Mrs. Ronald F. Brown), grandchildren Carol Ann and Ronald Trent, sister Pauline of Park Ridge, Ill., and brothers Carol G. of Mattoon, Ill., and Forrest C. of Burbank, Calif., survive him. He was a kind and loving father and husband with a highly developed sense of family responsibility. His family

is joined in mourning for him by a host of friends who have lost a good friend of sterling character with a keen sense of right and wrong, who never failed to take the right course. The art of exploration for minerals in the United States has lost one of its pioneers who had acquired intensive training in several branches of prospecting, established the broad principles of general, "environmental" exploration, and retained his equanimity in the face of adversity.

L. W. BLAU

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CARL MARION WERT

Mr. Carl Wert, age 48, underwent surgery in an Oklahoma City hospital on July 4th, but did not recover. He passed away July 18th. Funeral services were held in Henryetta, Oklahoma, July 21st at the First Methodist Church, with burial in the Westlawn cemetary.

Carl was a veteran employee of the Gulf Oil Corporation, and a member of the Society of Exploration Geophysicists since 1940. He was born in Mexico, Juniata County, Pennsylvania, on March 28, 1912. He attended the Westinghouse High School and Carnegie Institute of Technology, both of Pittsburgh, Pennsylvania. Carl joined Gulf Research & Development Company in June 1929 as an assistant in the Gravity Department. Approximately 1932, he transferred to seismic work and traveled over the Midcontinent states, receiving promotions as Gulf's seismic work expanded. In 1947, as party chief, he embarked on a 3-year foreign assignment with a crew which worked in Nicaragua and Cuba. While living in Fort Worth, Texas, from 1950 to 1957, he served Gulf in the capacity of geophysical supervisor. During this period, he was elected to the office of Secretary-Treasurer by the Fort Worth Geophysical Society for a one-year term. He was a member of the North Texas Geological Society. Mr. Wert

transferred to Wichita Falls, Texas, in November 1958 as Staff Geophysicist, the position he held at the time of his death.

As an actively dedicated 32nd Degree Mason, Carl was a member of the Masonic Blue Lodge, and of the Valley of Guthrie Consistory. Also, he was active in the Methodist Church, serving as Sunday School teacher and President of the Men's Club.

Carl and Edna Turk, of Maud, Oklahoma, were married December 23, 1934. Typical of our migratory profession, their first son was born in Oklahoma, and the second in Texas. The older son, Peter, is married and serving in the U. S. Navy with an NROTC Commission.

The second son, Turk, was killed in a hunting accident in February 1959. While a friend was unloading a gun, it accidentally discharged and ended the career of a very promising boy at the age of 15. Turk was an outstanding athlete, and in addition had received many awards as an honor student. The many friends of the Wert family assisted in establishing a Turk Wert memorial at Stripling Jr. High School, Fort Worth, Texas. It consists of a plaque on which is engraved annually the name of the student who does the most with his inherent abilities. The student receiving this award also receives a replica of the plaque which hangs in the school library.

Other survivors besides his wife and son include Carl's father, S. V. Wert, Columbus, Ohio; three brothers, Jerry Wert, Thompsontown, Pennsylvania; Wilbur Wert, Mifflintown, Pennsylvania; Dane Wert, Harrisburg, Pennsylvania; two sisters, Mrs. Faye McCormick, Detroit, Michigan; and Mrs. Carol Jean O'Conner, Germany.

Those who knew Carl remember him as a true friend. He always left people with smiles on their faces, and feeling happy because of the contact with him. With his untimely passing, our profession losses a member dedicated to its application.

W. B. ROBINSON

## LETTERS TO THE EDITOR

# THE EFFECT OF TEMPERATURE ON THE RESPONSE OF SCINTILLATION COUNTERS*

A. F. GREGORY AND A. L. FOURNIER

It has been known for some years that the output of scintillation crystal-photomultiplier tube assemblies is temperature dependent (Kinard, 1957; Connor and Husain, 1960). Under certain circumstances, the counting rate may vary with the temperature but this response variation is also dependent upon the spectrum of pulses being investigated and upon the minimum pulse size which can be counted.

Temperature effects have not generally been considered in geophysical investigations with scintillation counters. Recently, a significant variation in counting rate with temperature ($-1$ to $-4$ percent per degree centigrade) was observed by the writers during a field investigation of the gamma radioactivity of natural mineral sources. This effect is probably negligible for ordinary prospecting purposes but may be important in certain quantitative aspects of ground, airborne and well-logging surveys in which the instrument temperature is not controlled.

In the work reported here, the variation of counting rate with temperature has been determined for four different detectors with a pitchblende source. Brief descriptions of the four instruments and their observed response-temperature coefficients are given in the accompanying table. As there may be large differences in temperature sensitivity between two photomultiplier tubes of the same type (Kinard, 1957), the response-temperature coefficients probably will be peculiar to the crystal-photomultiplier assembly and the spectrum for which it was determined.

TABLE

| Crystal | Photo-multiplier | Detector | Response-Temperature Coefficient | Observed Temperature Range | Source |
|---|---|---|---|---|---|
| 3 inch×1¾ inch diam. NaI(Tl) | Dumont 6292 | EA-136S airborne scintillation counter | −4.0%/°C.<br>−2.2%/°F. | 56–72°F. | 90 lbs. pitchblende (approximately 15% $U_3O_8$) at 5 feet and 12 feet from crystal |
| 3 inch×3 inch diam. NaI(Tl) | Dumont 6363 | Detecting element prepared for use with a 100 channel kicksorter, C.D.C. model A.E.P.-2230 | −2.3%/°C.<br>−1.3%/°F. | 20–25°C. | vial of pulverized pitchblende at 2½ inches from crystal |
| 4 inch×2 inch diam. NaI(Tl) | RCA 5819 | M.E.L. type A.E.P. 1903R Mark II airborne scintillation counter | −1.3%/°C.<br>−0.7%/°F. | 66–86°F. | 90 lbs. pitchblende (approximately 15% $U_3O_8$) at 17½ feet from crystal |
| 1 inch×1 inch diam. NaI(Tl) | RCA 6199 | PRI model 111 | probably small, but data not definitive. Possibly 0.5 to 1.0%/°C. | 61–66°F. | 90 lbs. pitchblende (approximately 15% $U_3O_8$) at 5 feet from crystal |

* Published with permission of the Director, Geological Survey of Canada.

The EA-136S and PRI-111 detectors are self-contained, portable units. For these instruments, the counting rate variation was measured for different ambient air temperatures. The M.E.L. unit has crystal, photomultiplier and preamplifier enclosed in a light-tight box comprising $\frac{1}{8}$-inch aluminum sheeting with $\frac{1}{4}$-inch aluminum cover. In this instance, the temperature is that registered by a thermometer bulb located inside the box at the crystal end of the assembly and about $\frac{1}{4}$ inch from the end of the box. The photomultiplier and crystal used with the C.D.C. kicksorter were housed in a box of thin aluminum and pine sheeting. This housing restricted but did not prohibit ventilation during the tests. The preamplifier was located in an adjacent but separate ventilated compartment. The thermometer bulb was placed next to the crystal container.

The variation of counting rate with temperature for the M.E.L. unit (Figure 1) is typical of the variations for the other instruments.

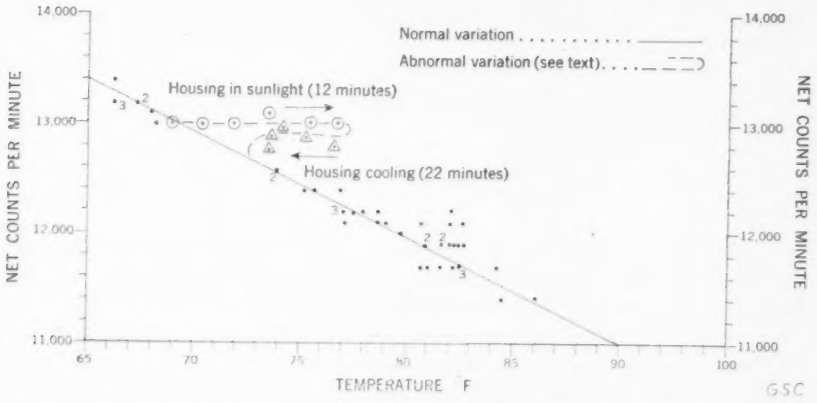


FIG. 1. Typical graph showing variation of response with temperature (June/59).
Detector: M.E.L., type AEP 1903R, Mk II., #2 counter only. 4″ ×2″ diam. NaI(Tl) crystal, RCA 5819 photomultiplier.
Source: 90 lbs. pitchblende (approximately 15% $U_3O_8$) at 17½ feet from crystal.
Response-temperature coefficient: −0.7 percent per degree fahrenheit.
−1.3 percent per degree centrigrade.

In measuring response-temperature coefficients, care should be taken to confirm that the measured temperature is that of the crystal-photomultiplier assembly. Apparent divergency from the normal variation may result from the heat of direct sunlight falling on the metal housing of the detector. Such an effect was observed for the M.E.L. detector (*see* Figure 1). It is probable that the housing absorbed heat and reradiated it to the nearby thermometer. The crystal and photomultiplier in the center of the insulating air mass apparently did not warm up to the same extent. Thus, upon replacement of the cardboard shade protect-

ing the housing from direct sunlight, the divergent part of the curve returned to follow the normal response-temperature variation. Similar effects were observed with the other detectors.

Net counting rates were also compared with air density, background counting rate and time but no correlation was found.

The observed variation of counting rate with temperature of the scintillation crystal-photomultiplier tube assembly may be important in ground, airborne and well-logging surveys in which the radiometric data are contoured or compared as to magnitude, especially with high counting rates. For ordinary prospecting, in which radioactivity maxima are recognized relative to the background of adjacent rocks, these temperature effects are not likely to be significant.

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## ON THE CALCULATION OF AFMAG* ANOMALIES

JAMES R. WAIT†

It has been proposed by S. H. Ward (1959) and C. S. Wright et al. (1960) that nonuniformity in the earth's crust will tend to tilt the direction of the fluctuating components of the geomagnetic field from its normal horizontal direction. In fact, Ward and colleagues have developed a practical scheme (AFMAG) for geophysical prospecting which makes use of this phenomenon in the frequency range from 100 to 400 c/s. Sir Charles Wright et al., on the other hand, have found that at much lower frequencies, .005 to 1 c/s, a substantial vertical component of the field in the vicinity of coast lines or other situations where the earth's crust departs from horizontal stratification.

It is the purpose of this short note to show how these anomalies may be calculated for certain idealized situations. Actually, the problem is closely related to those in electromagnetic prospecting using artificial fields.

At least for frequencies in the ELF (extremely low frequencies, meaning the range 1 to 3.00 c/s), the origin of the fields are from lightning discharges (Pierce 1960). In fact Holzer and others (1957) have shown that there is a high correlation between the world-wide thunderstorm activity and the integrated level of the noise in this frequency range. For frequencies below 1 c/s the origin of the fields is not yet understood. It is probable that they are related to current sys-

* AFMAG—Audio Frequency Magnetics.

† Newmont Exploration Ltd., Danbury, Connecticut.

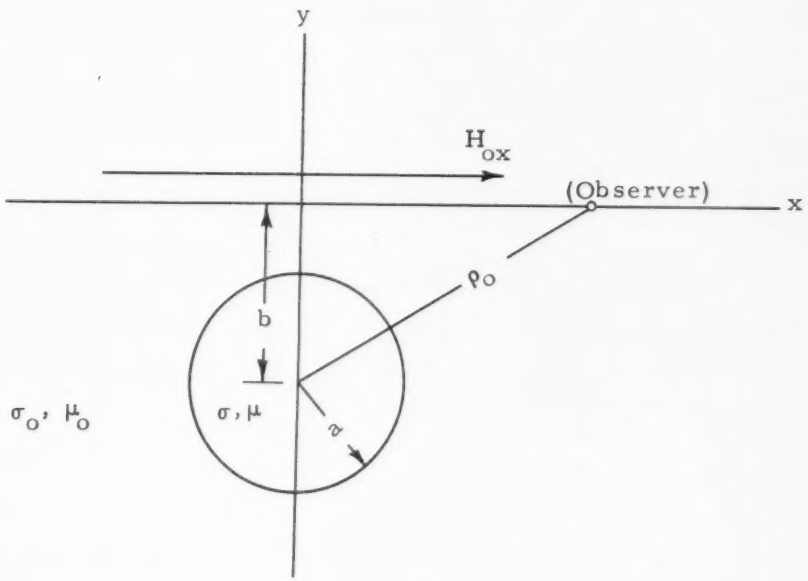


FIG. 1

tems at ionospheric heights which themselves are induced by solar particles (Campbell 1960). In any case, at the surface of a homogeneous smooth earth the fluctuating component would be horizontal or approximately so (Wait 1960a).

For purposes of illustration, the earth is assumed to be locally flat, thus it can be represented as a homogeneous half space, of conductivity $\sigma_0$ and permeability $\mu_0$, defined by $y<0$.[1] The surface of the earth is the $xz$ plane. Within the earth and running parallel to the $z$ axis is an infinite cylinder of radius $a$, of conductivity $\sigma$ and permeability $\mu$. The axis of the cylinder is located at $y=-b$ in the piane $x=0$. In view of the nature of the problem, it is only the perpendicular or $x$ component of the exciting magnetic field $H_0$ which needs to be considered. Furthermore, because of the assumed uniformity of the exciting field $H_{0x}$ at the surface, it can be assumed to decay exponentially with depth. Thus the field which acts on the cylinder may be taken as $H_{0x}\exp(-\gamma_0 b)$ where $\gamma_0=(i\sigma_0\mu_0\omega)^{1/2}$. Such a field will induce a line dipole at $y=-b$. Higher-order poles can be neglected if $|\gamma a|\ll 1$ or if $a\ll b$. It will be assumed that such a condition is met. The strength of this induced line dipole can be readily computed by making use of known results (Wait 1960b). However, obtaining the resultant fields of the line dipoles at the surface is not so straight-forward since the boundary conditions at the air-ground interface (i.e., $y=0$) must be met. In principle, the

[1] See Fig. 1.

solution can be obtained but it is not of much use until some of the integrals can be evaluated. (This problem is now being investigated.) As a rough approximation, it is assumed that the resultant fields are those derived by magneto-statics (strictly valid if $\gamma_0=0$) but then multiplied by the correction factor $\exp(-\gamma_0\rho)$ where $\rho=(b^2+x^2)^{1/2}$ is the distance from the axis of the cylinder to the observer at the surface.

A straight-forward derivation yields the following for the surface fields

$$\frac{H_x}{H_{0x}} \cong 1 + T\left[\frac{a^2}{x^2+b^2} - \frac{2x^2a^2}{(x^2+b^2)^2}\right] \exp\left[-\gamma_0(x^2+b^2)^{1/2} - \gamma_0 b\right]$$

and

$$\frac{H_y}{H_{0x}} \cong -T_1\left[\frac{2xba^2}{(x^2+b^2)^2}\right] \exp\left[-\gamma_0(x^2+b^2)^{1/2} - \gamma_0 b\right],$$

where

$$T_1 = -\left[\frac{(\mu/\mu_0)I_1(i^{1/2}X) - i^{1/2}XI_1'(i^{1/2}X)}{(\mu/\mu_0)I_1(i^{1/2}X) + i^{1/2}XI_1'(i^{1/2}X)}\right],$$

and $X=(\sigma\mu\omega)^{1/2}\,a$, $I_1$ is the modified Bessel function of order one and the prime indicates a derivative with respect to its argument.

Numerical values of the complex factor $T_1$ have been given previously (Wait 1960b). For a highly conducting body, such that $X\ll 1$, $T_1$ approaches $+1$. For $X\ll 1$ it is readily shown that

$$T_1 = -\frac{\mu-\mu_0}{\mu+\mu_0}$$

which could be obtained directly from magneto-statics. For intermediate values of $X$ the imaginary part of $T_1$ is finite which means that there is a phase shift between the $H_y$ and $H_x$. In any case, it is seen that right over the cylinder, the magnitude of $H_y$ has a maximum. It is given by

$$\left|\frac{H_y}{H_{0x}}\right|_{x=0} \cong = \frac{T_1a^2}{2b^2} \exp\left[-(2\sigma_0\mu_0\omega)^{1/2}b\right].$$

For low frequencies, such that $(\sigma_0\mu_0\omega)^{1/2}\,b\ll 1$, and if the depth $b$ is, say, $3a$, the vertical component would never be more than 6 percent of the undisturbed horizontal field.

This approach may be used for other models such as a buried wedge or knife edge. While the method is certainly not rigorous it should be useful for obtaining first-order estimates. In the case of two-dimensional bodies it is necessary to consider the induced electric dipoles. These would be proportional to the electric (or telluric) field.

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## CONTRIBUTORS

Z. F. DANES

Z. F. DANES was educated at Charles University in Prague, Czechoslovakia, where he received his Ph.D. equivalent in Mathematics and Physics in 1949. From 1945 till 1947, he was Research Assistant with the State Geophysical Institute in Prague, and from 1948 till 1950, Assistant Professor of Physics at the University in Pilsen. In 1951, he organized a company translating Russian and other Slavic geophysical publications into Western languages.

From 1953 till 1959 he was a Geophysicist with the Gulf Research and Development Company in Pittsburgh, Pennsylvania, and since 1959 he has worked as Geophysicist with the Boeing Airplane Company in Seattle, Wash. He is a member of the Board of Directors of the Applied Radionics Corporation.

In 1950, he was granted an award of the Czech National Research Council for his developments in geomagnetic instrumentation. His main field is theoretical geomagnetism, the theory of gravitational interpretation methods, and the gamma-gamma density logging. At present he is working on the geomagnetic aspects of plasma physics.

DR. A. F. GANGI was born February 19, 1929 in Newark, New Jersey. He received his B.S. and M.S. degree in Applied Physics from the University of California, Los Angeles, California in 1953 and 1954, respectively. He received his Ph.D. degree in Physics from U.C.L.A. in 1960.

From 1955 to 1960 he was a Senior Electronics technician and Research Associate at the Institute of Geophysics at U.C.L.A. During that time he designed and performed experiments in elastic wave propagation using Seismic models. He also did theoretical work in elastic wave propagation and boundary value problems.

At present he is a member of the Technical Staff in the Research and Development Department of Space Electronics Corporation, Glendale, where he is working on theoretical problems in communication theory and on boundary-value problems associated with VLF propagation.

DR. A. F. GANGI

WILLIAM B. JOYNER

WILLIAM B. JOYNER was born in Casper, Wyoming, in 1929. He received an A.B. in geology in 1951, an A.M. in geophysics in 1952, and a Ph.D. in geophysics in 1958, all from Harvard University. During the summers of 1952 and 1953 he was employed by the United States Geological Survey doing electrical and magnetic prospecting. His graduate study included work in gravity, earth temperatures, and rock magnetism. He is now employed by the Humble Oil and Refining Company.

L. KNOPOFF is a Professor of Geophysics at the Institute of Geophysics of the University of California. He has been at the University of California since 1950.

ROLLIN E. PHIPPS

ROLLIN E. PHIPPS received his B.S. degree in geology from the University of Nebraska in 1950. He did graduate work at the university until 1951. Mr. Phipps was associated with Stanolind from 1951 to 1955. He also worked in Louisiana and West Texas for United Geophysical Company. In 1956 he joined Lion Oil Company as geophysical assistant to the Chief Geologist in El Dorado, Arkansas. At the present time, he is supervising geophysical exploration in the Southwestern Region for the Lion Oil Division of Monsanto Chemical Company.

Mr. Phipps is a member of the SEG, Permian Basin Geophysical Society and the I.P.A.A. He was a charter member of the Jackson Geophysical Society.

EUGENE M. WESCOTT

EUGENE M. WESCOTT was born February 15, 1932, in Hampton, Iowa, and moved to southern California in 1942. In 1955 he received a B.A. from U.C.L.A. in earth physics and exploration geophysics. For the next three years he was employed in geophysical research on uranium exploration by the U. S. Atomic Energy Commission, in Denver, Colorado. In 1958 he began graduate work at the Colorado School of Mines, then transferred to the University of Alaska, where he received an M.S. in geophysics in 1960. He is currently working towards a Ph.D. degree at the Geophysical Institute, University of Alaska. His professional society memberships include SEG and AGU.

A biography of K. VOYOFF appeared in GEOPHYSICS July 1958, v. 23, no. 3, p. 601.

# SOCIETY ROUND TABLE

## COMMITTEES FOR THE YEAR ENDING IN NOVEMBER 1960

### EXECUTIVE COMMITTEE

*President:* T. O. HALL, General Geophysical Company, Houston, Texas
*First Vice-President:* FRANK SEARCY, Continental Oil Company, Ponca City, Oklahoma
*Vice-President:* DEAN WALLING, Western Geophysical Co. of America, Los Angeles, California
*Secretary-Treasurer:* PHIL P. GABY, Consultant, Jackson, Mississippi
*Editor:* NELSON C. STEENLAND, Gravity Meter Exploration Company, Houston 27, Texas
*Past President:* E. V. MCCOLLUM, E. V. McCollum & Company, Tulsa, Oklahoma

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E. V. MCCOLLUM
O. C. CLIFFORD, JR.

### Tellers

JAMES F. JOHNSON, *Chairman*

### Honors and Awards

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R. C. DUNLAP, JR. ('62)
ROY F. BENNETT ('63)
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SAM TEASLEY
ROBERT L. TUCKER

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(To be appointed)

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NORMAN H. RICKER
JOSHUA L. SOSKE
S. H. WARD
ISIDORE ZIETZ

### Index of Wells

V. U. GAITHER, *Chairman*

### Case Histories

D. P. CARLTON, *Chairman*

### Geophysical Activity

H. G. PATRICK, *Chairman*
K. L. COOK
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HERBERT HOOVER, JR.
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LORENZ SHOCK
DANIEL SILVERMAN
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C. C. SELLERS, JR.

### Delegates to I.U.G.G.

JACK OLIVER ('60)
W. A. HEISKANEN ('60)

## LOCAL SECTIONS

**Ark-La-Tex Geophysical Society (6),** Shreveport, La., chartered March 12, 1949, officers elected in May. *Meetings:* Monthly, last Monday, noon luncheon ($1.50), Captain Shreve Hotel.
Virgil Teufel, *pres.*
J. A. Boydstun, *v-pres.*
R. H. Wardell, *secty-treas.*, Western Geophysical Co., 322 Fairfield Bldg., Shreveport, La.

**Canadian Society of Exploration Geophysicists (9),** Calgary, Alta., chartered January 24, 1952, officers elected in February. *Meetings:* Monthly, no set schedule.
Dr. M. B. Dobrin, *pres.*
P. J. Savage, *vice-pres.*
J. J. Hamilton, *secty.*, Canadian Society of Exploration Geoph., Shell Oil Co. of Canada, Ltd. P.O. Box 880, Calgary, Alta., Canada.
J. G. Goodwin, *treas.*

**Casper Geophysical Society (11),** Casper, Wyoming. Chartered May 23, 1953, officers elected in May. *Meetings:* Monthly, 1st Monday, 7:00 P.M., dinner ($2.75), Townsend Hotel, Casper, Wyoming.
G. L. Ellis, *pres.*
B. A. Tuller, *v-pres.*
Robert Davenport, *secty-treas.*, Wyoming Seismograph Co., Box 631, Casper, Wyoming.

**Coastal Bend Geophysical Society (24),** Corpus Christi, Texas, chartered May 29, 1959, officers elected in May.
Walter Pfennig, *pres.*
J. W. Bolinger, *v-pres.*
James Vetters, *treas.*
B. C. Johnson, *secty.* Forest Oil Corp., Box 1356, Corpus Christi, Texas.

**Cochabamba Geophysical Society (23),** Cochabamba, Bolivia, chartered May 4, 1959, officers elected in December.
R. H. Matthews, *pres.*
Charles W. Hyatt, *v-pres.*
Noel C. Manning, *secty.-treas.*, Geophysical Service Inc., Casilla #1437, Cochabamba, Bolivia.

**Dallas Geophysical Society (4),** Dallas, Texas, chartered August 7, 1948, officers elected in December. *Meetings:* Monthly, usually 2nd Monday, 8:00 P.M., Fondren Science Bldg., Southern Methodist University.
E. F. McMullin, *pres.*
F. J. McDonal, *1st v-pres.*
E. J. Jasinski, *2nd v-pres.*
S. C. Mut, *secty-treas.*, The Atlantic Refining Co., P.O. Box 2819, Dallas 21, Texas.

**Denver Geophysical Society (8)**
*Meetings:* Monthly, 1st Monday, 5:30 P.M., dinner at 7:00 P.M. ($3.00), Petroleum Club, Denver.
John C. Hollister, *pres.*
Arthur W. Black, *v.-pres.*
Charles E. McMunn, *secty-treas.* Tower Exploration Inc., P.O. Box 156, Englewood, Colorado.

**Geophysical Society of Edmonton (22),** Edmonton, Alta., Canada, chartered March 20, 1959, officers elected in December.
A. S. Gibson, *pres.*
R. F. Keller, *v-pres.*
R. D. Jacques, *secty-treas.*, Mobil Oil of Canada, Ltd., Financial Bldg., Edmonton, Alta.

**Fort Worth Geophysical Society (5)**
O. A. Strange, *pres.*
R. H. Dana, *v.-pres.*
U. A. Rowe, *secty.*
C. H. Thurber, *treas.*, Champlin Oil and Refining Co., Box 9365, Forth Worth, Texas.

**Four Corners Geophysical Society (19),** Durango, Colo., and Farmington, N. M., chartered June 19, 1958, officers elected in May.
J. P. Badami, *pres.*
F. E. Endacott, Jr., *1st v-pres.*
J. F. Wright, *2nd v-pres.*
G. D. Sindorf, *treas.*
L. E. Schneider, *secty.*, Empire Geophysical, Inc., Box 1484, Durango, Colo.

**Geophysical Society of Houston (2),** Houston, Texas, chartered February 14, 1948, officers elected in May. *Meetings:* Monthly, noon luncheon.
D. P. Carlton, *pres.*
S. P. Worden, *1st v-pres.*
K. A. Webb, *2nd v-pres.*
S. M. Pena, *treas.*
J. L. Bible, *secty.*, 1045 Esperson Bldg., Houston 2, Texas.

**Jackson Geophysical Society (15)**
J. J. Babb, *pres.*, Delta Exploration Co.
T. H. Tillman, *v-pres.*, Sun Oil Co.
James M. Watson, *secty.-treas.*, Humble Oil & Refining Co., P.O. Drawer No. 1490, Jackson 5, Mississippi.

**Montana Geophysical Society (14),** Billings, Mont., chartered April 12, 1954, officers elected in December. *Meetings:* Monthly, 2nd Monday, 7:30 P.M., Billings Petroleum Club.
W. H. Dawson, *pres.*
Phil Hendrick, *1st v-pres.*
F. J. Felice, *2nd v-pres.*
Max Judy, *secty.-treas.*, Sun Oil Co., Box 1896, Billings, Mont.

**New Mexico Geophysical Society (18),** Roswell, N. M., chartered September 18, 1957, officers elected in May.
R. E. Lawson, *pres.*
Delmer M. Woods, *1st v-pres.*
T. E. Daly, *2nd v-pres.*
R. W. Aldrich, *secty.-treas.*, Mobil Oil Co., 714 Petroleum Bldg., Roswell, N.M.

**Geophysical Society of Oklahoma City (10),** Okla. City, Okla., chartered September 30, 1952, officers elected in May. *Meetings:* Monthly, 2nd or 3rd Monday.
A. J. Oden, *pres.*
C. L. Howell, *1st v-pres.*
H. J. Fenton, *2nd v-pres.*
W. S. Hart, *treas.*
E. M. Peacock, *secty.*, Sohio Petroleum Co., 1606 N. Broadway, Oklahoma City, Okla.

**Pacific Coast Section (3),** luncheon ($2.75) Rodger Young Auditorium, Los Angeles.
F. F. Lambrecht, *pres.*
Nolan A. Webb, *v-pres. S.D.*
Fred G. Knight, *v-pres. N. D.*
Tom Slaven, *secty.-treas.*, Western Geophysical Co. of America, 523 W. 6th St., Los Angeles, Calif.

**Permian Basin Geophysical Society (7),** Midland, Texas, Chartered January 30, 1950, officers elected in December. *Meetings:* Monthly, 2nd Tuesday, 7:30 P.M., Midland Women's Club.
J. E. Clark, *pres.*
E. E. Fickenger, *1st v-pres.*
B. H. Hinton, *2nd v-pres.*
S. T. Miller, *treas.*
L. M. Scofield, *secty.*, Burton Exploration Co. Inc., 4513 W. Storey, Midland, Texas.

**Regina Geophysical Society (22)**
A. C. Armstrong, *pres.*
M. MacIver, *v-pres.*
J. R. Muir, *secty.-treas.*, The California Standard Co., 1836 Smith St., Regina, Saskatchewan, Canada.

**Geophysical Society of South Texas**
J. W. E. Edmonson, *pres.*
P. J. Rudolph, *v-pres.*
Donald W. Jones, *secty.-treas.*, Sun Oil Co., 832 Milam Bldg., San Antonio, Texas.

**Southeastern Geophysical Society (13),** New Orleans, La., chartered April 1, 1954, officers elected in January. *Meetings:* Monthly, 3rd Monday, noon luncheon ($2.00), Monteleone Hotel.
George Morgan, *pres.*
J. T. McMaster, *1st v-pres.*
D. R. Scheel, *2nd v-pres.*
O. J. Rauschenbach, *secty.-treas.*, Continental Oil Co., 414 Carondelet Bldg., New Orleans 12, La.

**Southwest Louisiana Geophysical Society (16),** Lafayette, La., chartered January 4, 1956, officers elected in December.
Jack Wallner, *pres.*
Walter Hurt, *1st v-pres.*
Richard Hollenbaugh, *2nd v-pres.*
Ned Pratt, *treas.*
Lucius Geer, *secty.*, Union Oil of California, Box 1224 OCS, Lafayette, La.

**Geophysical Society of Tulsa (1)**
Tulsa, Okla., chartered February 2, 1948, officers elected in May.
T. S. Green, *pres.*
J. E. Hawkins, *1st v-pres.*
K. S. Cressman, *2nd v-pres.*
B. L. Bass, *secty.*, Geophysical Society of Tulsa, Texaco, Inc., P.O. Box 2420, Tulsa, Okla.
Robert B. Fisher, *treas.*

**Utah Geophysical Society (17)**
L. D. Oster, *pres.*
K. L. Cook, *1st v-pres.*
H. H. Nuttli, *2nd v-pres.*
D. J. O'Halloran, *secty.-treas.*, Standard Oil of California, P.O. Box 1076, Salt Lake City Utah.

**Asociacion Venezolana de Geofisica** (20), Caracas, Venezuela, chartered January 5, 1959, officers elected in March.
E. J. Assiter, *pres.*
D. W. Danz, *2nd v-pres.*
Manuel Zegarra, *secty.*, Asociacion Venezolana de Geofisica, Phillips Petroleum Co., Apartado 1031, Caracas, Venezuela.
C. O. Hill, *treas.*

STUDENT SOCIETIES AFFILIATED

**Colorado School of Mines Society of Student Geophysicists**
Joseph R. Anzman, *secty.* Department of Geophysics, Colorado School of Mines, Golden, Colorado.
*Meetings:* Monthly, 2nd Monday, 4:00 P.M.

**Geophysical Society of Saint Louis University**
Norman J. Guinzy, *secty.* 410 Vandalia, Collinsville, Illinois.
*Meetings:* Monthly, 2nd Wednesday 7:30 P.M., meeting only, Institute of Technology.

**SEG Houston Student Section**
Billie Gail Dopsauf, *secty.* 2121 Hollister, Houston, Texas

**University of Toronto Geophysical Society**
B. R. Krause, *secty.* 502 Gilbert Ave., Apt. 107, Toronto, Ont., Canada

**University of Tulsa Student Geophysical Society**
Fred D. Munzlinger, *secty.* Department of Geophysics, 600 South College, Tulsa, Oklahoma.
*Meetings:* Weekly, Thursday, 4:00 P.M., Petroleum Science Bldg.

**Trans-Pecos Student Section**
El Paso, Texas

**Pennsylvania State University Geophysical Society**
Wm. R. England, *secty.* College of Mineral Industries, University Park, Pa.
*Meetings:* to be announced.

**University of Utah Geophysical Society**
James D. Morgan, *secty.* College of Mines and Mineral Industries, Salt Lake City 1, Utah.
*Meetings:* Monthly, 1st Thursday Noon, Mines Building. Other special meetings to be announced.

**A & M College of Texas Student Geophysical Society**
Edward C. Hanson III, *secty.* Geology and geophysics dept., A & M College of Texas, College Station, Texas.

## SOCIETY AFFILIATIONS

### American Association for the Advancement of Science

*SEG is affiliated under Section E, Geology and Geography*
1515 Massachusetts Avenue
Washington 5, D. C.
Paul E. Klopsteg, *President*
Paul A. Scherer, *Treasurer*
Dael Wolfle, *Executive Officer*

### The American Association of Petroleum Geologists

*A Cooperative relationship*
Box 979
Tulsa 1, Oklahoma
L. G. Weeks, *President*
A. H. Bell, *Vice-President*
H. T. Morley, *Secretary-Treasurer*
G. E. Murray, *Editor*
G. S. Buchanan, *Past President*
R. H. Dott, *Executive Director*

### European Association of Exploration Geophysicists

*Mutually affiliated*
30, Carel Van Bylandtlaan
The Hague, Netherlands
J. M. Bruckshaw, *President*
V. Baranov, *Vice-President*
B. Baars, *Secretary-Treasurer*
O. Koefoed, *Editor*
L. Solaini, *Past President*

### National Research Council, Division of Earth Sciences

*SEG is a member society*
2101 Constitution Ave., N.W.
Washington 25, D. C.
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Harry H. Hess, *Past Chairman*
Edward B. Espenshade, Jr., *Chairman-Designate*
William R. Thurston, *Executive Secretary*

### Petroleum Exploration Society of Libya

*Mutually Affiliated*
P. O. Box 900
Tripoli, Libya
R. E. Doan, *President*
P. F. Burollet, *1st Vice-President*
J. F. Romminger, *2nd Vice-President*
J. C. Wilson, *Secretary*
P. Arni, *Treasurer*
J. S. Cullison, *Director*
R. S. M. Templeton, *Director*

## MEMBERSHIP APPLICATIONS RECEIVED

Applications for active membership have been received from the following candidates. This publication does not constitute an election but places the names before the membership at large, in accordance with Bylaws, Article III, Section 4. References are listed in parentheses following the names of each candidate. If any member has information bearing on the qualifications of these candidates he should send it to the president within thirty days.

### APPLICATIONS FOR ACTIVE MEMBERSHIP

E. R. Critchett (W. J. Ricker, Jr.; N. Vander Sleen, E. E. Smith)
Gilbert, Freeman (R. Bowman, M. K. Smith, M. M. Backus, E. J. Stulkew)
John E. McCall (S. C. Stoneham, W. L. Besham, T. L. Slaven, R. E. Doe)
Kenneth J. Parry (H. R. McCormack, J. M. Desmond, R. J. Koenig, J. Swistek)
James H. Pennington (Chester Sappington, R. J. Hope, J. D. Laker, J. S. Spencer)

### APPLICATIONS FOR TRANSFER TO ACTIVE MEMBERSHIP

Donald C. Bowman (J. F. Johnson, A. C. Reid, H. J. Jones, D. R. Oksa)
Daniel F. Brennan (C. M. Moore, Jr., K. E. Burg, R. C. Dunlap, Jr., Neil W. Mann)
James W. Buelow (L. Y. Faust, A. I. Innes, K. M. Lawrence, F. F. Campbell)
Perry E. Byerly (W. H. Diment, R. M. Hazelwood, Rudolph Black, H. R. Joesting)
Frank Clynch (J. M. Crawford, Frank Searcy, L. E. Whitehead, W. E. N. Doty)
Gunter Wm. Conrad (C. N. Page, C. J. Lomax, A. E. McKay, W. A. Seal, Jr.)
Theodore R. Dunn (S. B. Stewart, D. G. Coppedge, D. B. Darden, S. A. Hatcher)
John O. Erickson (J. W. Keffler, Earl M. Wolters, H. L. Mendenhall, W. H. Courtier)
Morris F. Gillett (E. L. DeLoach, C. H. Hightower, M. S. Hathaway, J. P. Woods)
John C. Healy (J. Athanasion, Richard L. Fentem, Wm. M. Krum, J. B. Nichols)
Herr, Wilfred C. (E. B. Miller, C. H. Gullick, L. E. Whitehead, L. K. King)
Thomas C. Holt (T. O. Hall, M. H. Collum, R. J. Watson, Dale Turner)
Jason S. Johnson (M. G. Frey, Alton McClung, E. J. Grivetti, E. J. Northwood)
James B. Jordon (F. J. DiGuilio, B. B. Strange, N. P. Cramer, Dean Walling)
Ernest A. Kaarsberg (Warren Westphal, J. T. Wilson, T. C. Poulter)
John W. Keeler (S. R. Marsh, E. J. Laurent, J. D. Sollenberger, J. A. Dunn)
Wm. E. Kelley (H. R. Hockoday, W. K. Rickel, J. T. Gilliam, R. C. Roesch)
Robert F. Kraye (Lee B. Park, Robert J. Knott, Will Alex Grosse)
Laidlaw, Wm. H. (R. J. Yuzbick, H. C. McCarver, L. V. S. Roos)
Sam R. Lake (W. T. Lea, R. W. Buhrman, John W. Bell, Jr., Glenn E. Hunter)
Lawyer, Leon C. (J. K. Pawley, R. B. Wilcoxen, J. C. Kern)
Harold R. McCormack (R. J. Koenig, J. Swistek, J. A. MacMillan, J. J. O'Bertos)
Donald K. McIvor (J. B. Murphy, D. C. Skeels, C. J. Chapman, J. T. Hughson)
Montgomery, John A., Jr. (J. H. Wright, Jr., Miles T. Rader, W. J. Pfeffer, G. B. Neville)
John R. Muir (F. A. Hale, W. A. Robertson, G. C. Alvey, H. Agnew)
John J. O'Bertos (H. R. McCormack, R. J. Koenig, J. MacMillan, J. Swistek)
Chas. G. Oldham (F. G. Blake, N. A. Riley, G. D. Garland, L. P. Stephenson)
Glenn Robertson (G. H. Samuels, O. G. Holekamp, C. H. Gregory, F. W. Oudt)
Donal E. Ruminer (W. H. Roane, W. H. Courtier, F. H. Morris, J. M. Sanders)
Henry B. Sawatzky (D. H. Parry, M. C. Woodard, A. Armstrong, R. H. Carter)
James Wm. Schneider (C. B. Smith, S. B. Stewart, C. C. Sellers)
Edward Thiel (J. P. Woollard, A. P. Crary, K. L. Cook, W. E. Bonini)
Howard F. Thompson (C. Newton Page, Robert J. Knott, Wm. A. Seal, Jr.)
Wm. M. Walton, Jr. (J. H. Wright, Jr., M. T. Rader, W. J. Pfeffer, D. C. Meyer)

# ANNOUNCEMENTS

## SPECIAL ISSUE ON ENGINEERING GEOPHYSICS

Plans are under way for a special issue of GEOPHYSICS devoted to engineering geophysics. The editor has appointed Dr. Charles L. Drake, Lamont Geological Observatory, Palisades, New York, Chairman of a special editorial committee for the volume. Tentatively the December, 1961, issue has been chosen to feature engineering geophysics papers.

Members of the society are invited to submit papers on engineering geophysics to Dr. Drake, whose committee will have the responsibility of reviewing all submitted papers for the special issue before their submittal to the editor.

Dr. Drake has appointed Howard Pincus, Ohio State University, Columbus, to serve on the committee with him. Other members of the committee will be appointed soon.

## GEOPHYSICS ON MICROFILM

Volume 21 through 24 of GEOPHYSICS, 1956 through 1959, are now available, one reel per volume as follows:

| | |
|---|---|
| Volume 21 (1956) | $4.45 |
| Volume 22 (1957) | 3.95 |
| Volume 23 (1958) | 4.60 |
| Volume 24 (1959) | 4.60 |

Complete with tables of contents, indexes, and advertising, these microfilmed volumes may be purchased direct from University Microfilms, Ann Arbor, Michigan.

## GEOPHYSICAL SOCIETY ESTABLISHES BEST PAPER AWARD

The Canadian Society of Exploration Geophysicists announces the establishment of an annual "Best Paper" award. One hundred dollars will be awarded for the best paper presented during the year at one of the several meetings sponsored by the Society. The author must be a resident of the Calgary area, but need not be a member of the Society.

Judges, four in number, include R. B. Ross of British American Oil Company Ltd., D. C. Skeels of Imperial Oil Limited, A. Junger of Shell Oil Co. of Canada Ltd., and G. J. Blundun of Home Oil Co. Ltd.

Funds for the awards will be provided by the publishers of *Canadian Oil and Gas Industries*.

## A JOURNAL OF THE AMERICAN INSTITUTE OF PHYSICS IS NOW A MONTHLY

*The Physics of Fluids*, a journal of the American Institute of Physics, will be published monthly instead of bimonthly, effective with Vol. IV (1961). Inquiries should be sent to: American Institute of Physics, 335 East 45 Street, New York 17, N. Y.

## PERSONAL ITEMS

HARRY W. CARLSON, formerly with the California Company, is now a consultant in seismic interpretation. His new address is 726 Guaranty Bank Bldg., Denver, Colorado.

ED FRITZ, with Pure Oil Company, has been transferred to Houston as Chief Geophysicist, Southern Division

JACKSON W. BROWN, formerly Domestic Manpower Administrator for GSI, is now College Relations Coordinator with Texas Instruments, Inc.

ERNEST H. HUME, Senior Seismic Computer with Humble, is on loan to Esso-Republic, Bordeaux, France. His assignment is geophysical interpretation of Esso-Republic permits.

ROBERT H. MANSFIELD is now Supervisory Geophysicist, USAF (AFTAC), at: HQ-USAF (AFTAC), Washington 25, D. C.

EDWARD D. LYNTON has a complete set of GEOPHYSICS from Vol. I, No. 1 (Jan. 1936) to Vol. XX, No. 4, (Oct. 1955), including the bound Cumulative Index 1931 through 1953. He has priced them at $1.50 per copy but will consider any reasonable offer. They will be sold only as a set, not as individual copies. His address is 422 Beloit Ave., Berkeley 8, California.

ROBERT VAN NOSTRAND's address is 23 Rue Galilée, Paris 16, France, not as erroneously quoted on page 725 of the June issue of GEOPHYSICS.

DR. JULIAN F. EVANS, who holds his Ph.D. degree from Rice University and has been employed by the Pan American Petroleum Corp. research division for the past 19 years, joined the University of Tulsa faculty Thursday as an assistant professor of mathematics.

A native of Michigan, he received a bachelor of arts degree in English from the University of Oklahoma in 1926 and a master of science degree in physics in 1932.

He received his Ph.D. degree in physics from Rice in 1939. From 1940–41 he taught physics, geophysics and mathematics at Texas Christian University. Dr. Evans then joined the Pan American geophysical research department.

He is a member of Phi Beta Kappa and Sigma Xi honor societies and the Society of Exploration Geophysicists.

Western Geophysical Company of America, a subsidiary of Litton Industries, has moved into its newly completed four-story headquarters building adjacent to its laboratories and shops at 933 North La Brea Ave., Los Angeles, California.

CARLTON D. SPEED, transportation chairman for the Houston Geological Society, headed a group of 26 Houston Geologists and their families who toured Western Europe before attending the International Geological Congress in Copenhagen on August 14.

EDWIN B. NEITZEL, former Technical Supervisor of Atlantic Refining's Geophysical Laboratory, has accepted a position as Engineering Group Head in the Collins Radio R and D IV Department. He will be working on computer data processing problems.

DOYLE D. MIZE, vice-president and Houston manager of Mandrel Industries, has been named executive vice-president in charge of all Mandrel operations.

The announcement was made following the first meeting of the Board of Directors of Mandrel Industries held in Houston.

Mr. Mize was appointed operations manager of Electro-Technical Laboratories in 1951. When Mandrel purchased Electro-Tech in 1956, Mr. Mize was appointed a vice-president.

In 1958 Mr. Mize became head of the Electric Sorting Machine division, assuming responsibility for the entire Houston operations.

In 1959, he was elected to the Mandrel Board of Directors.

Prior to his association with Mandrel, Mr. Mize was technical and field operation supervisor for a leading geophysical company.

Mr. Mize attended the University of Houston and majored in chemistry. He is a member of both the Society of Exploration Geophysicsts and the Houston section.

A native of Iola, Texas, Mr. Mize, his wife and six children reside at 807 Chowning Rd., Houston.

DANIEL LUM, formerly geophysicist with the South Dakota Geological Survey, recently completed gravity surveys on the islands of Bohol, Cebu, and Mindoro, Philippines, under contract assignment to Atha Exploration Co. of Los Angeles, California. Mr. Lum is presently residing in Honolulu, Hawaii.

PETER C. SUNDT will be chief administrator and technical director of Mandrel's two Houston divisions, Electro-Technical Labs and Electric Sorting Machine Company.

Mr. Sundt, who graduated from Lamar High School before entering Rice, began his career as an engineer with Hughes Aircraft Company. He came to Electro-Technical Labs in 1953 as a design engineer.

He has since been chief engineer and general manager of Electro-Tech France with headquarters in Paris.

He was called to Houston from France to accept the new position.

Mr. Sundt is a member of the Houston Geological Society, Institute of Radio Engineers, and the Society of Exploration Geophysicists.

He and Mrs. Sundt and their three children will make their home in Houston.

KENNETH S. TOWNSEND has resigned his position as Station Manager for Birdwell Division of Seismograph Service Corporation to take a position as Geophysicist with Sunray Mid-Continent Oil Company in Tulsa.

EUGENE MCDERMOTT, Chairman of the Executive Committee of Texas Instruments Incorporated in Dallas, Texas, has been named to the Stevens Institute of Technology Board of Trustees.

Mr. McDermott is a 1919 Stevens graduate. He entered the oil exploration field in 1925 when he helped found the Geophysical Research Corporation.

In 1930 he co-founded Geophysical Service Incorporated, thus sharing in the development of geophysical exploration techniques still considered the most reliable and economic means of locating oil deposits in the earth.

Mr. McDermott served as President of St. Mark's School for Boys in Dallas from 1945 to 1955 and continues as a Trustee. He is Co-founder and Trustee of the Graduate Research Center of Dallas, member of the Executive Committee and Board of Trustees of the Texas Research Foundation, and a Trustee of the Hockaday School for Girls in Dallas.

His other memberships include the Southwestern Medical Foundation, and the Visititing Committee on Physics of the Massachusetts Institute of Technology. He also serves on such boards as the Dallas Art Museum and the Dallas Theater Center. Mr. McDermott is a past president of the Society for Exploration Geophysicists.

Mr. McDermott is one of twenty-five Stevens trustees who serve five year terms. Three other trustees elected from the alumni body serve for three years.

BERNARDO F. GROSSLING, formerly with California Research Corp., has joined the Inter-American Development Bank, Washington, D. C. His present position is Acting Chief, Engineering Division.

FRANK GOLDSTONE, erroneously reported in August GEOPHYSICS as having entered into partnership with Geoprosco of London, is in fact representing Petty Geophysical Engineering Company in their London office.

Professor ENDERS A. ROBINSON of the Mathematics Department of the University of Wisconsin will spend the academic year 1960–1961 at Statistiska Institutionen vid Uppsala Universitet, Jarnbrogatan 18, Uppsala, Sweden.

J. BRIAN EBY, an independent consultant geologist in Houston, Texas since 1931, is now associated with Bradco Oil & Gas Co. Mr. Eby received his A.B. and Ph.D. degrees from Johns Hopkins University. Before going into consulting work, he served as a geologist with the U. S. Geological Survey and with Shell Petroleum Corp. Dr. Eby has lectured at Johns Hopkins, Princeton, University of Texas, Texas A & M College and other colleges and universities. He is the author of numerous technical articles on geology, and has traveled in Europe, Africa, Canada and Mexico as foreign representative for U. S. oil publications. Dr. Eby's professional memberships include AAPG, IPAA,

American Association for Advancement of Science, SEG; Texas Academy of Science, and Royal Society of Arts, London, England.

ODIE M. HOLMES (1937 to present), formerly with The Petty Geophysical Engineering Company, San Antonio, Texas, Rogers-Ray Geophysical Co. of Houston, Texas, and Seismic Analysis, Inc., Dallas, Texas, has recently gone into private practice as an Exploration Consultant, 4041 Rosa Road, Dallas 20, Texas.

COL. GEORGE B. KAISER USAF (Ret.), has recently been appointed Manager, Planning Programs for Robert O. Vaughan, the Vice-President of Marketing at Southwestern Industrial Electronics.

Col. Kaiser is a graduate of Texas A & M with a Masters Degree in Electrical Engineering and is a registered Professional Engineer in Texas. He is also an active member of the Institute of Radio Engineers, Society of Exploration Geophysicists, and American Association of Petroleum Geologists.

Index Geophysical Surveys Corp., 2707 Milam Street, Houston, Texas, announces the recent addition of NEAL CLAYTON to the staff as a Geophysical Supervisor. For the past twelve years Mr. Clayton was District Supervisor for Sohio Petroleum Company in Lafayette, Louisiana. Mr. Clayton, a graduate of L.S.U. with a Masters in Physics and Mathematics, has published a number of articles in *World Oil* and GEOPHYSICS during the past twelve years dealing with exploration problems. The new Supervisor is a native of Mississippi, and has had extensive experience in most of the active sedimentary basins of the United States in addition to the Texas and Louisiana Coasts.

Effective August 15th, the name of ELECTRO-TECH FRANCE will be changed to MANDREL CIE.

For reasons of overall convenience, the headquarters and manufacturing facilities of Mandrel Cie will be moved from Paris to Annecy (Haute Savoie), France. However, a sales office for Electro-Technical Labs. will be maintained at Paris.

The Paris sales office will be headed by GEORGE KARAMBERIS.

The new addresses are as follows:

| | |
|---|---|
| Mandrel Cie | Electro-Technical Labs.—Sales Office |
| 59, Avenue des Romains | 54, Avenue de Versailles |
| Annecy (Haute Savoie) | Paris 16 |
| France | France |

DAVID W. STRANGWAY has completed requirements for the Ph.D. degree in physics at the University of Toronto. He is employed as a research geophysicist for Bear Creek Mining Co., Denver, Colorado.

## CALENDAR OF MEETINGS

1961

February

19–23 AIME Annual Meeting, St. Louis, Missouri.

March

20–23 IRE National Convention, New York City.

April

9–11 Society of Exploration Geophysicists, 14th Annual Midwestern Meeting, Skirvin Hotel, Oklahoma City, Oklahoma.

24–27 AAPG-SEPM Annual Meeting, Denver, Colorado.

October

8–11 Society of Petroleum Engineers of A.I.M.E., Annual Meeting, Dallas, Texas.

18–21 AAPG Mid-Continent Regional Meeting, Amarillo, Texas.

25–27 Gulf Coast Association of Geological Societies, San Antonio, Texas.

November

2–4 GSA Annual Meeting, Cincinnati, Ohio.

5–9 Society of Exploration Geophysicists, 31st Annual International Meeting, Denver, Colorado.

9–10 Pacific Section AAPG, Los Angeles.

13–15 API, Chicago, Illinois

1962

March

15–16 Fort Worth Geophysical Society, 15th Annual Midwestern Exploration Meeting, Texas Hotel, Fort Worth, Texas.

26–29 AAPG-SEPM Annual Meeting, San Francisco, California.

26–29 IRE National Convention, New York City.

September

17–20 Society of Exploration Geophysicists, 32nd Annual International Meeting, Calgary, Alberta.

October

7–10 Society of Petroleum Engineers of A.I.M.E. Annual Meeting, Los Angeles, California.

31–Nov. 3 Gulf Coast Ass'n Geological Societies, New Orleans, La.

November

12–14 GSA Annual Meeting, Houston, Texas.

1963

March

25–28 AAPG-SEPM Annual Meeting, Houston, Texas.

October

6–9 Society of Petroleum Engineers of A.I.M.E. Annual Meeting, New Orleans, La.

24–28 Society of Exploration Geophysicists, 33rd Annual International Meeting, New Orleans, La.

November

13–16 Gulf Coast Ass'n of Geological Societies, Hot Springs, Ark.

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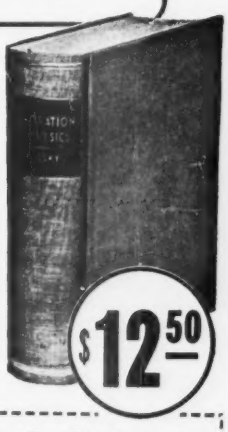


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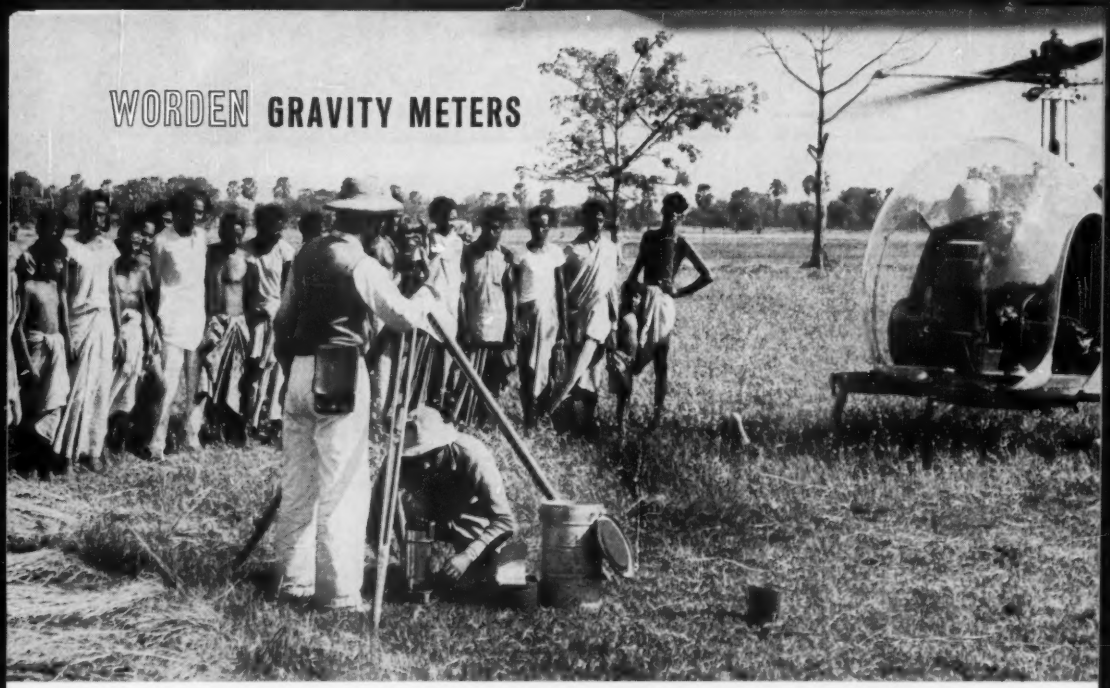


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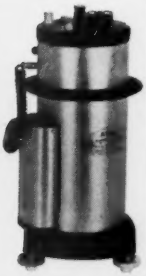

| When requesting a quotation, copy the specification categories in this column and specify the values desired from those found under the respective meters. | the *Master* | the *Prospector* | the *Pioneer* | the *Educator* |
|---|---|---|---|---|
| Minimum Recommended Operating Range—Specify to nearest 100 mgls.* plus latitude and elevation indication | 3000 mgls. | 3000 mgls. | 2400 mgls. | Limited . . . Will be at least 1600 mgls. |
| Minimum Total Operating Range (Reset) —Specify to nearest 100 mgls.* | 5200 mgls. | 5200 mgls. | 4000 mgls. | Limited . . . Will be at least 2000 mgls. |
| Small Dial Range | 800 Dial Divisions x Small Dial Constant (2200 on Special Order) | 800 Dial Divisions x Small Dial Constant (2200 on Special Order) | 800 Dial Divisions x Small Dial Constant | 800 Dial Divisions x Small Dial Constant |
| Small Dial Constant—Specify constant desired* | Standard .08 to .11 mgl./Dial Division (From 0.05-1.00 also available) | Standard .08 to .11 mgl./Dial Division (From 0.05-1.00 also available) | Standard .08 to .11 mgl./Dial Division (From 0.05-1.00 also available) | 0.10-1.00 mgl./ Dial Division |
| Small Dial Calibration Linearity over full range | 1 part in 1000 | 1 part in 1000 | 1 part in 1000 | 1 part in 1000 |
| Small Dial Reading Accuracy | 0.1 of Small Dial Division | 0.1 of Small Dial Division | 0.1 of Small Dial Division | 0.1 of Small Dial Division |
| External Temperature Control | Temp. Stabilizer requires 1.00 watts power for a 100° F. differential. Four Rechargeable "D" Size Batteries maintain 90° F. differential for 10 hours and are mounted in removable pack on side of meter. Any 4.5 to 12 volt DC source may be substituted. | None | None | None |
| Small Dial Mechanism | Self counting, read from top and directly coupled (no gears for backlash) with screw which contacts quartz measuring spring. | | Side and top reading, directly coupled (no gears for backlash) with screw which contacts quartz measuring spring. | |
| Large Dial Range — Specify range desired* | 800 Dial Divisions x Large Dial Constant | | | Geodetics not available |
| Large Dial Constant | Standard 6.5 to 12.0 mgls./D.D. | | | Geodetics not available |
| Large Dial Calibration over full range (8 turns) | Curve furnished with values accurate to one part in 1000—measured over full range (8 turns). | | | Geodetics not available |
| Size, Inches: Diameter Height | 7" 14" | 7" 14" | 5½" 10½" | 5½" 10½" |
| Weight, Pounds: Net Including carrying case | 9¾ lbs. 18 lbs. | 7½ lbs. 15¾ lbs. | 5⅛ lbs. 12 lbs. | 5⅛ lbs. 12 lbs. |
| *Price of meter is determined mostly by the Ranges and Dial Constant Specified. | | | | |

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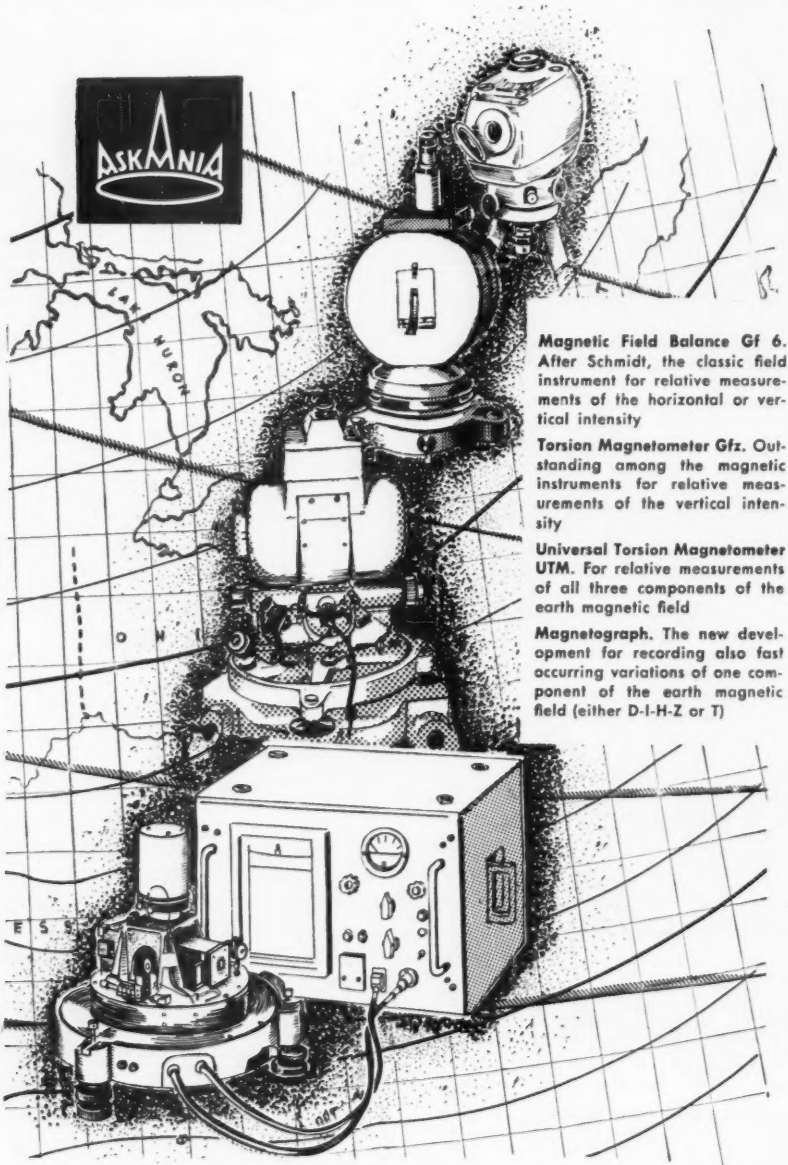


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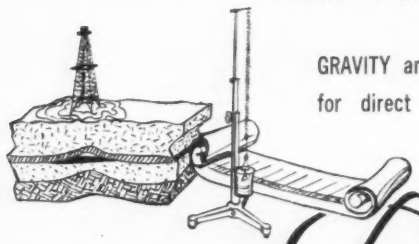

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*(Continued from page 9)*

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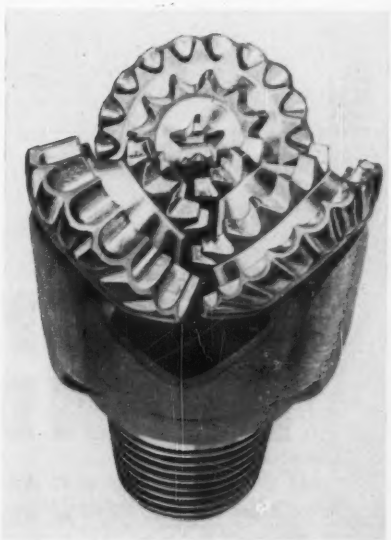

A new hard formation rotary rock bit, type VH1-C, is now available to the geophysical industry in sizes 4¼", 4½" and 4¾", according to **Varel Manufacturing Company, 9230 Denton Drive, Dallas 20, Texas.** This new bit has cup shaped teeth on the heel row which provides faster penetration in hard formations. The VH1-C is designed for fast drilling in hard abrasive formations. The "cup-shaped" teeth have cutting action on the back and both sides. The center teeth are more rugged to withstand heavier weights which are uesd in formations with high compressive strength. New VH1-C bits are already in the field and reports indicate extremely good reception from field crews.

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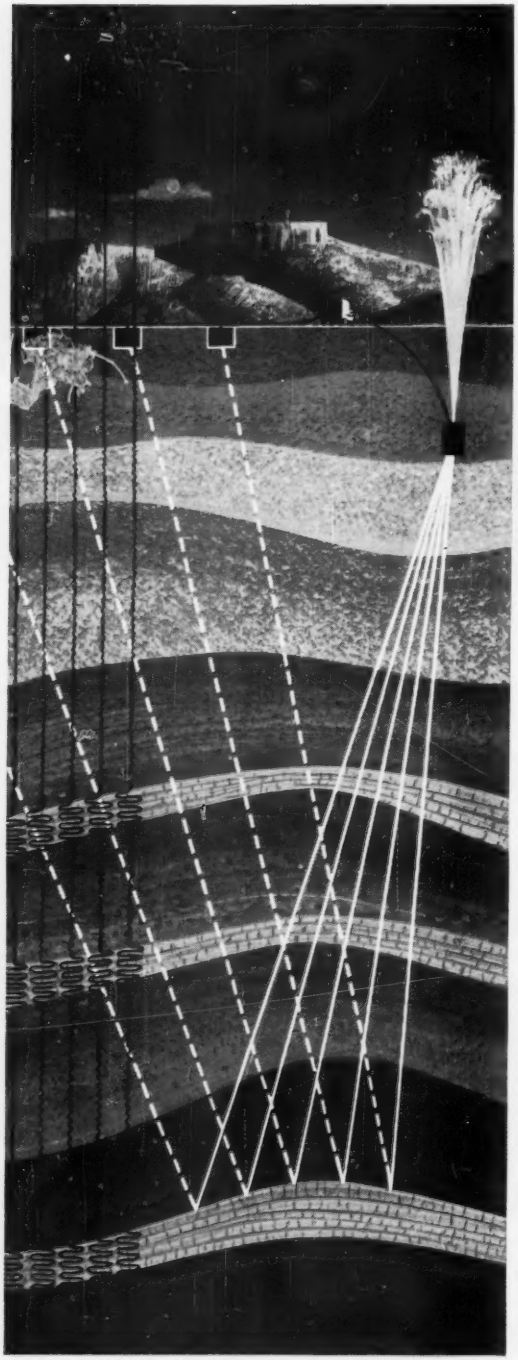
*(Continued on page 36)*



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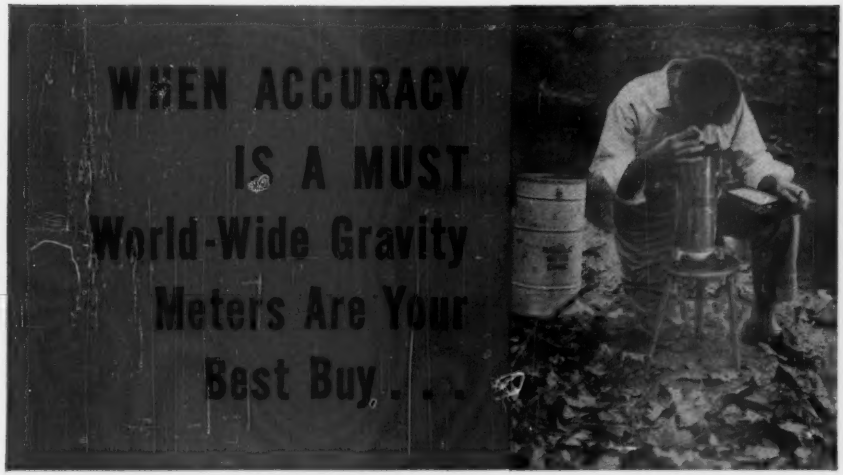


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*(Continued from page 31)*

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Model 411A is a compact, versatile unit which, according to the manufacturer, provides greater accuracy than any instruments of its kind. Accuracy from 1 MC to 50 MC is ±3% of full scale; 50 MC to 150 MC, ±6% of full scale, and 500 KC to 1,000 MC, ±1 db. Because of the millivoltmeter's high temperature stability, accuracy changes are negligible from 10° to 40° C.

Voltage range of the Model 411A is 10 millivolts rms full scale to 10 volts rms full scale in seven ranges. The unit provides full scale readings of 0.01, 0.03, 0.1, 0.3, 1, 3 and 10 volts rms.

Model 411A is equipped with a pen type probe tip, 500 KC to 50 MC. Extra screw-on probe tips include units for a high frequency measurement, for measuring on as well as at the termination of coax transmission lines, and a capacity divider increasing the instrument's voltage capability to 1,000 volts.

The Model 411A RF millivoltmeter is priced at $450. Its current availability is 9 weeks.

**Hewlett-Packard Company, 1501 Page Mill Road, Palo Alto, California.**

*(Continued on page 52)*

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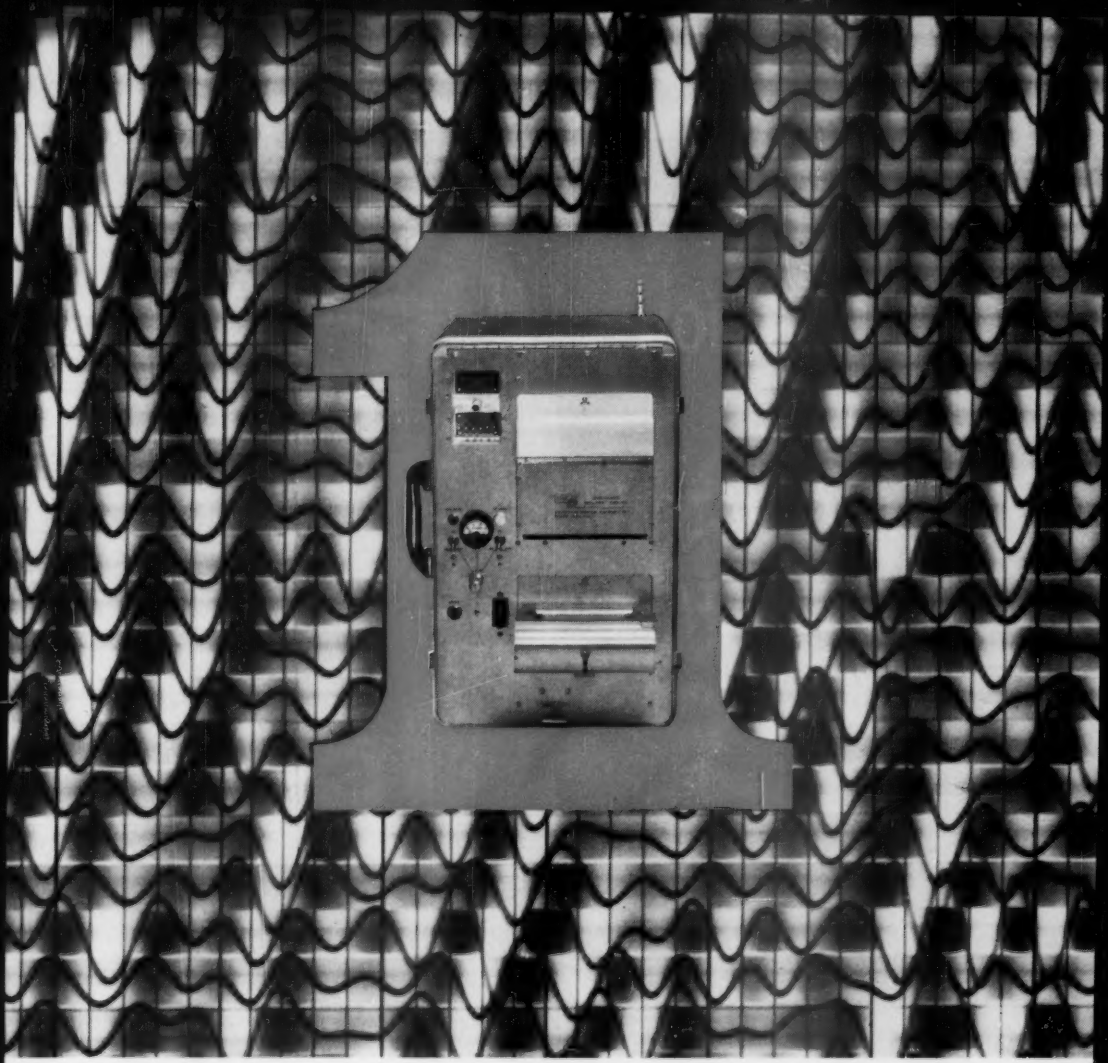

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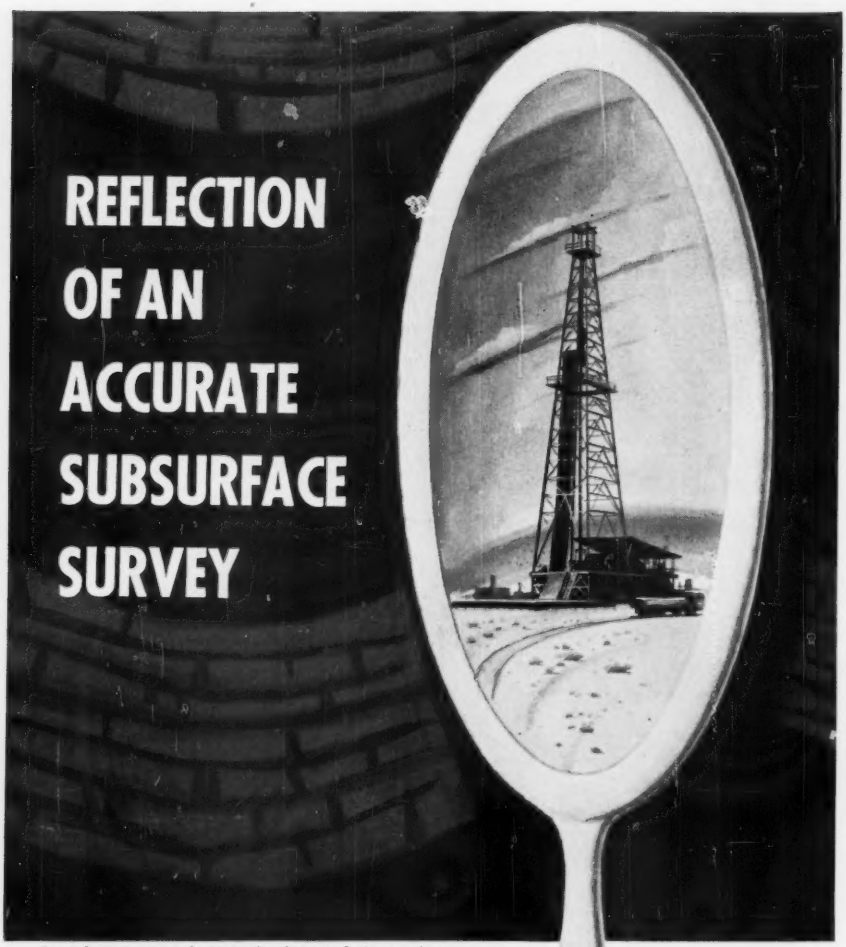


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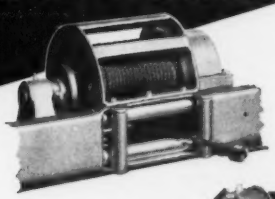

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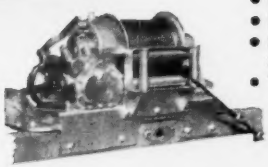

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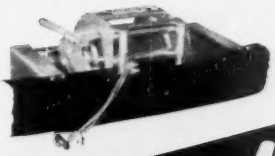

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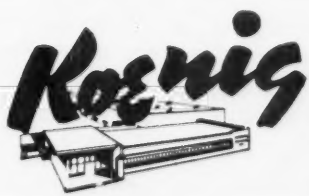


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PT-100 signal-handling capabilities are such that it will not overload in ANY area. And now you can record refraction with full AGC performance!

Forget about critical adjustments. Don't worry any more about distortion destroying the accuracy of your "picks"—you'll actually see improved reflection standout. At the same time enjoy all the other advantages of transistorized design. No more replacing parts like vacuum tubes to keep the channels balanced — transistors don't wear out.

All these "features" and a long list more are true bonuses. But most important to you if you want readable, reliable records is PERFORMANCE. Guess we'll just come right out and say it. The PT-100 is a **significantly** new amplifier.

So finally you challenge, "Prove it!" Only three steps are needed.

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2. Write for the PT-100 brochure. It's **complete;** we want you to know ALL about this amplifier.
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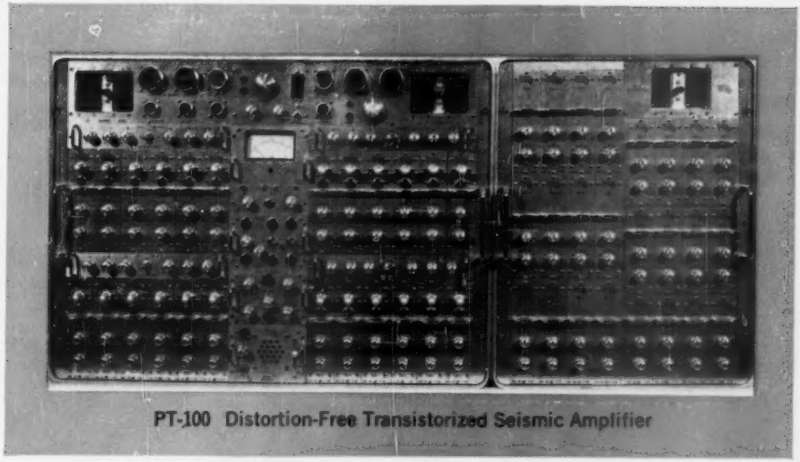

PT-100 Distortion-Free Transistorized Seismic Amplifier

**SIGNAL CONTROL**

With unique light-sensitive photocells as losser elements, the PT-100 eliminates the usual amplifier AGC problems. The critical "diode-balancing" common to other types of AGC circuits is never required. There is no direct electrical coupling between AGC and signal paths to cause distortion and oscillation. Signal voltages do not cause distortion when applied across losser elements as with diode bridge circuits. Drift and temperature instabilities are eliminated. There is a useful operating range of from one microvolt to one volt input — 1,000,000 to 1! Total harmonic distortion under all normal field operating conditions does not exceed 0.5% including heavy reflection standout. External 4 kc signals may be used for programmed-gain operation during amplitude studies. AGC performance down to 5 cps allows use of the PT-100 in refraction work **with AGC control.**

**FREQUENCY RESPONSE**

The broad band response extends from 3 to 500 cps. Low-cut filters are placed in the geophone line to eliminate ground roll distortion. Ten logarithmically-spaced cut-off frequencies are provided—from 16 to 135 cps for the low-cut and 23 to 235 cps for the high-cut filter positions. One or two sections (18 or 36 db/octave) may be used.

**NOISE**

Noise is less than 0.3 microvolt for "filter-out" bandpass and drops to 0.1 microvolt for normal filter settings—as good or better than most vacuum tube amplifiers.

**OPERATION**

Operator-oriented master controls provide separate record and playback adjustments for both "early" and "final" gain. Trimming adjustments for each channel are also provided. Complete built-in amplifier test units make testing and control adjustments rapid and easy.

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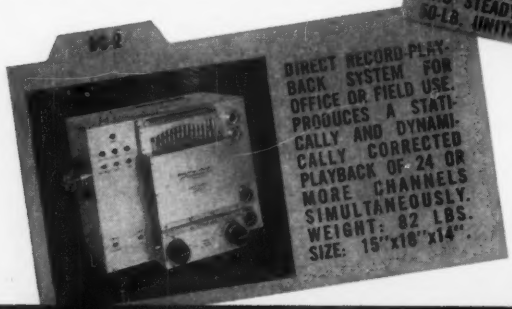

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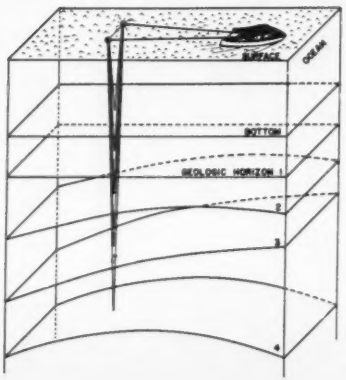


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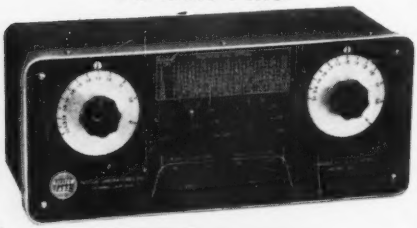

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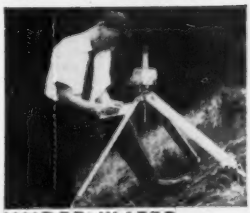

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### OBSERVATORY

Varian's V-4931 Modular Station Magnetometer **(proton)** is a highly versatile and accurate monitor of the earth's magnetic field. Strip-chart analog records and digital readout are supplemented by printed-tape output which may be engaged, as desired, to provide permanent digital records. The V-4934 Station Magnetometer **(rubidium vapor)** is particularly suitable for measuring and recording geomagnetic micropulsations.

### PORTABLE

The Varian M-49, a complete **proton** magnetometer weighing less than 20 lbs., furnishes direct readings in gammas every six seconds. Sensitive to better than ±10 gammas, it requires no calibration or levelling and is so versatile it can make equally accurate field records from surveys on land, in the air, or over water. Eight plug-in tuner ranges, equally spaced from 15,000 to 101,000 gammas, allow operation throughout the world.

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### OCEANOGRAPHIC

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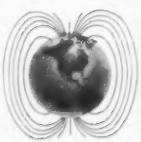

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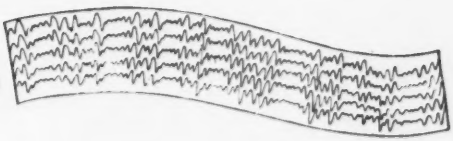

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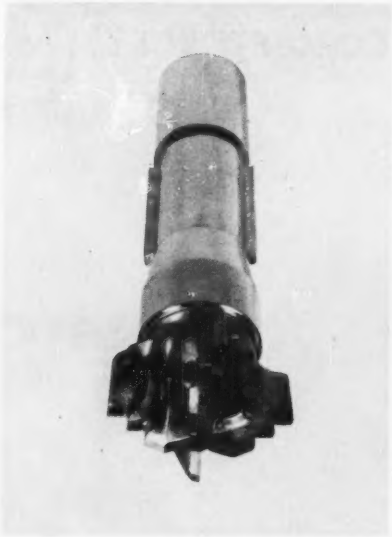

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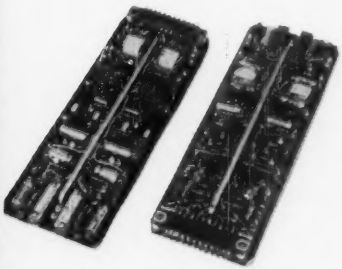

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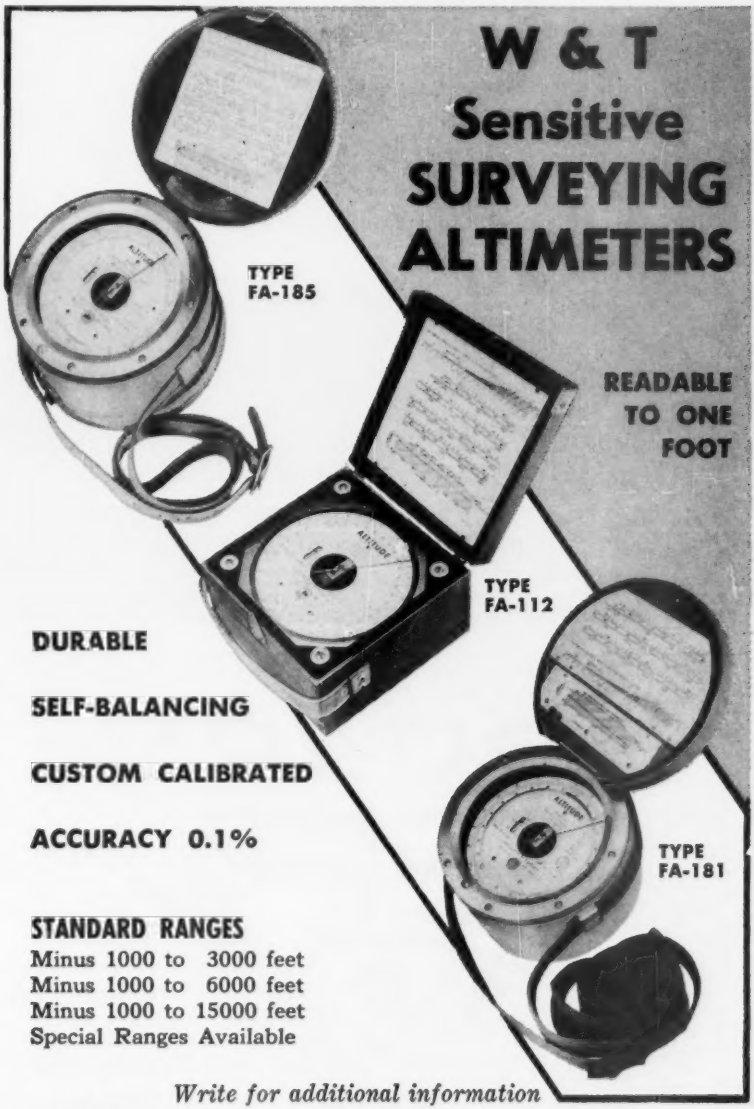


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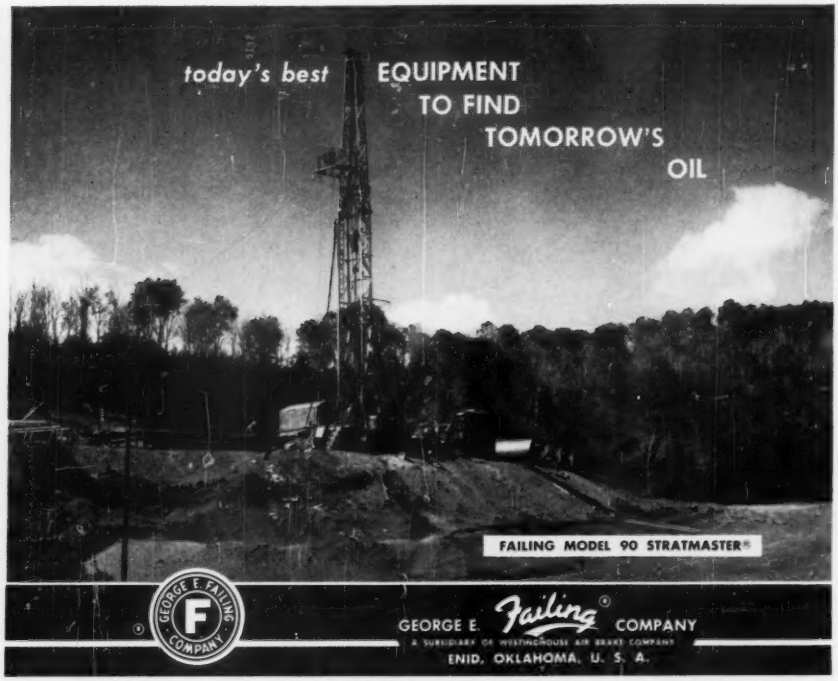


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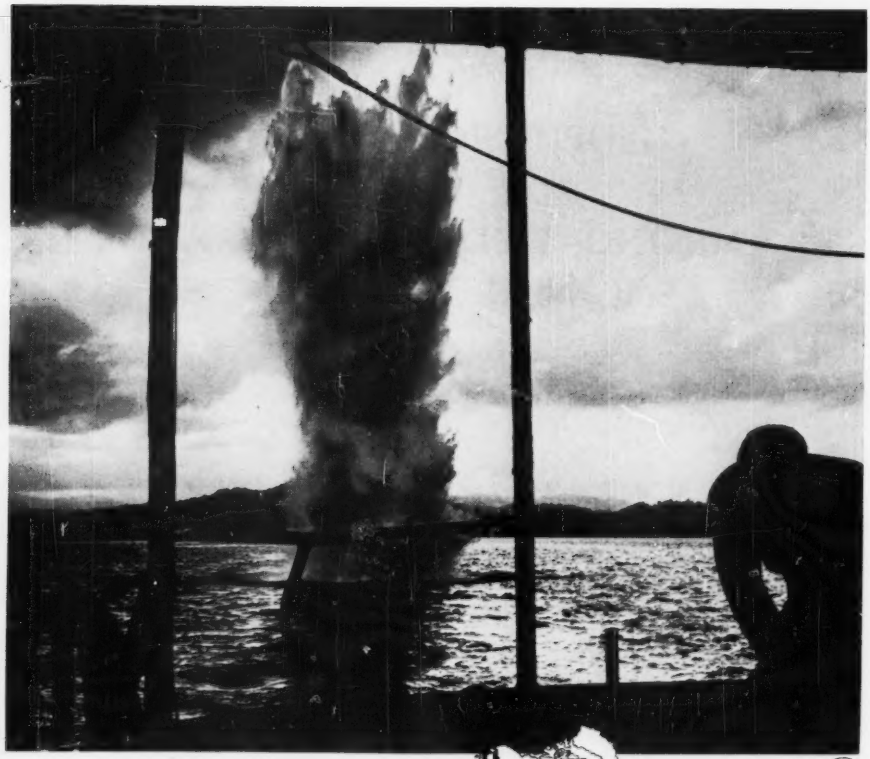

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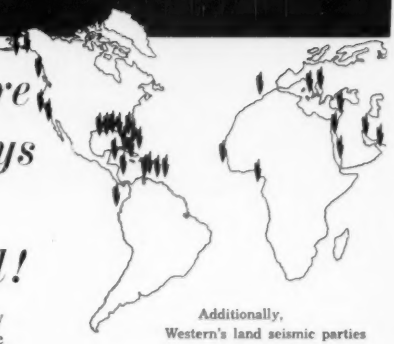

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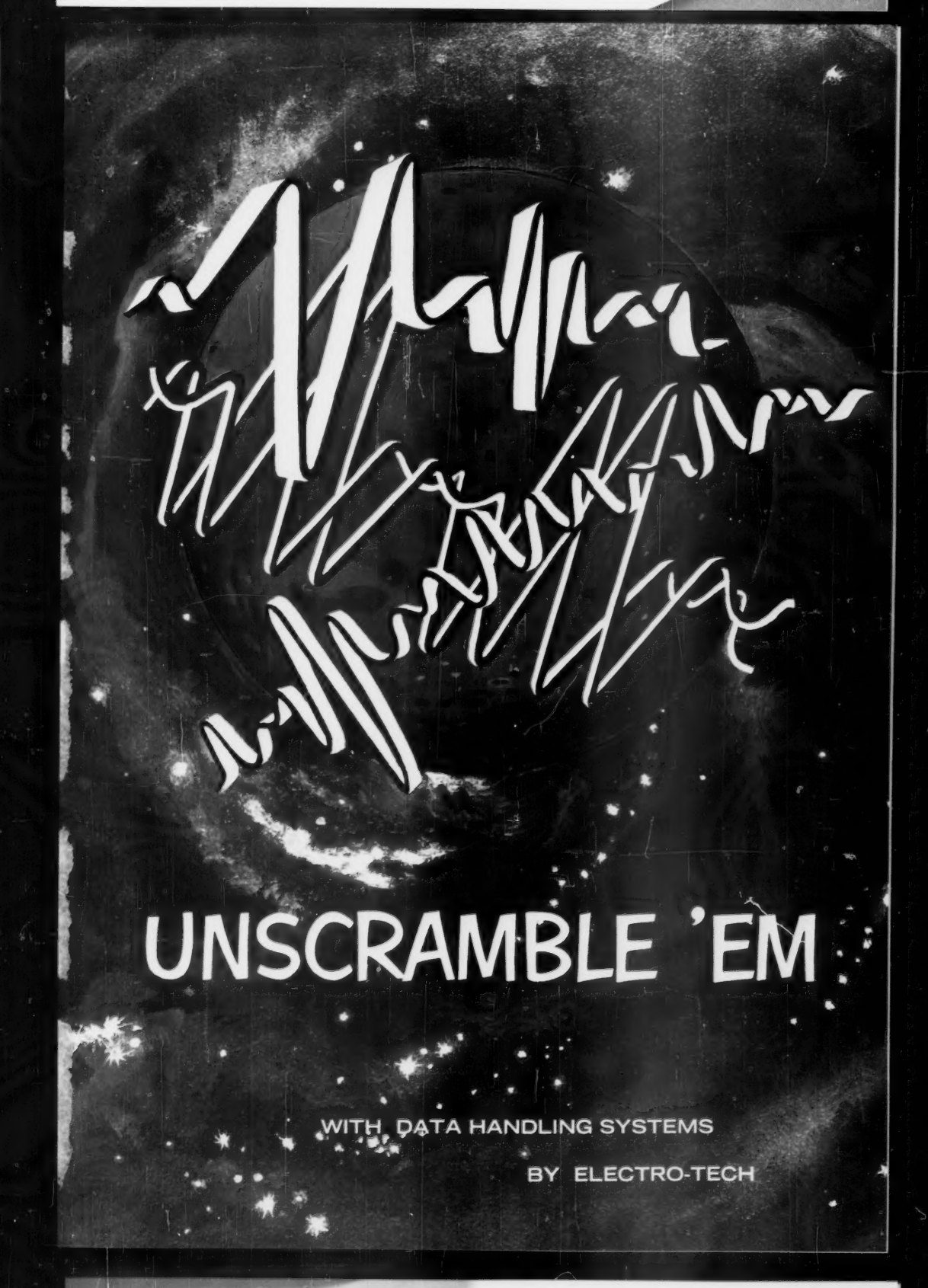
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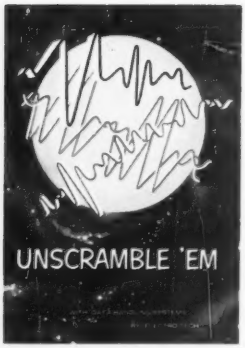


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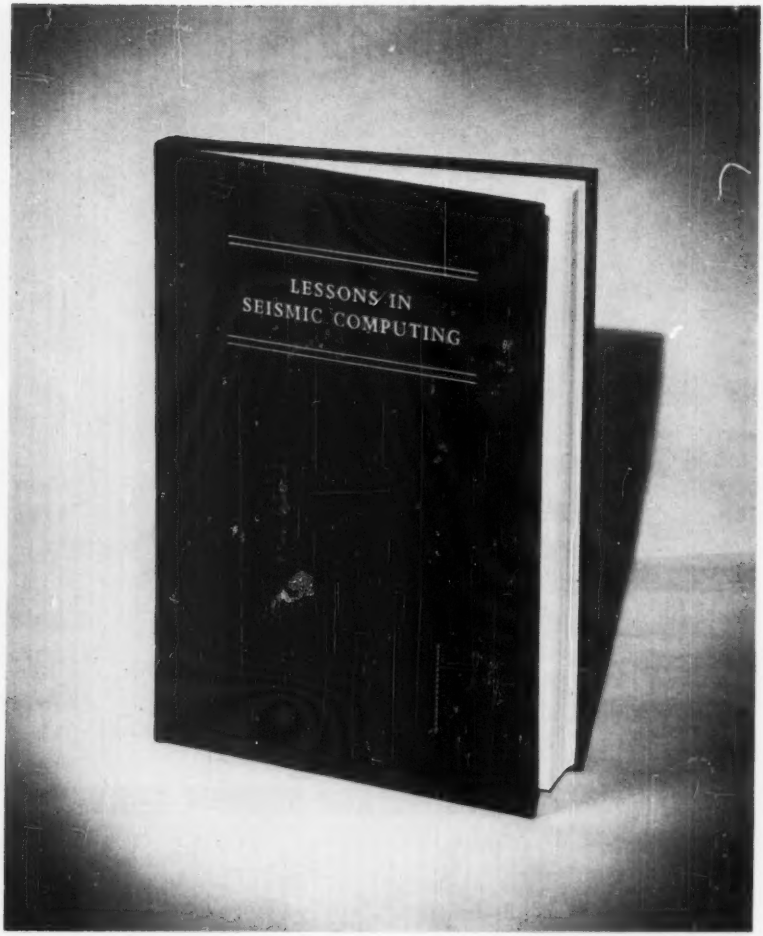


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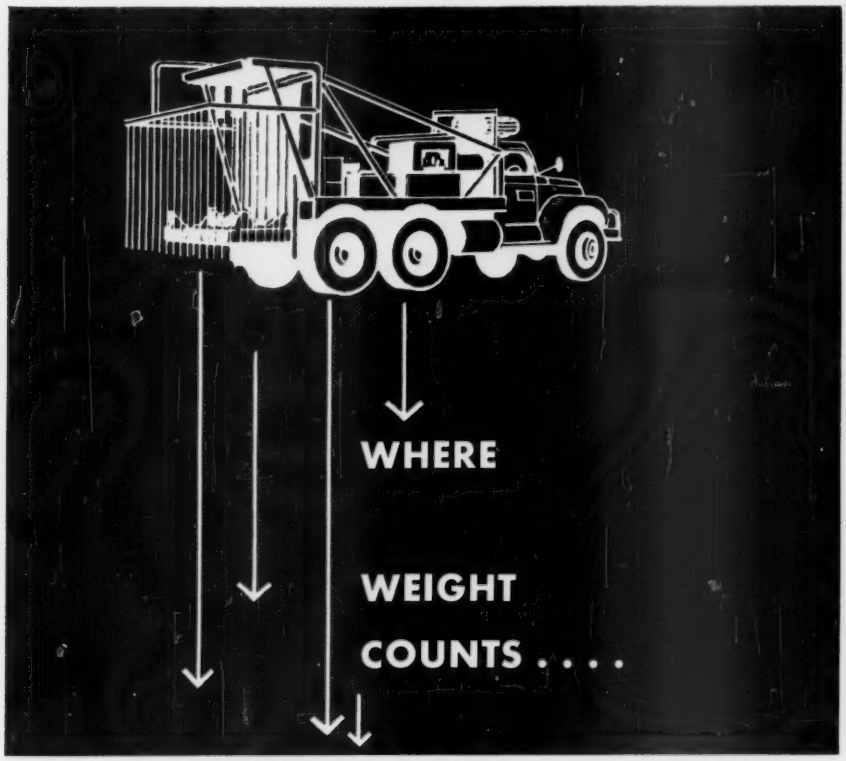


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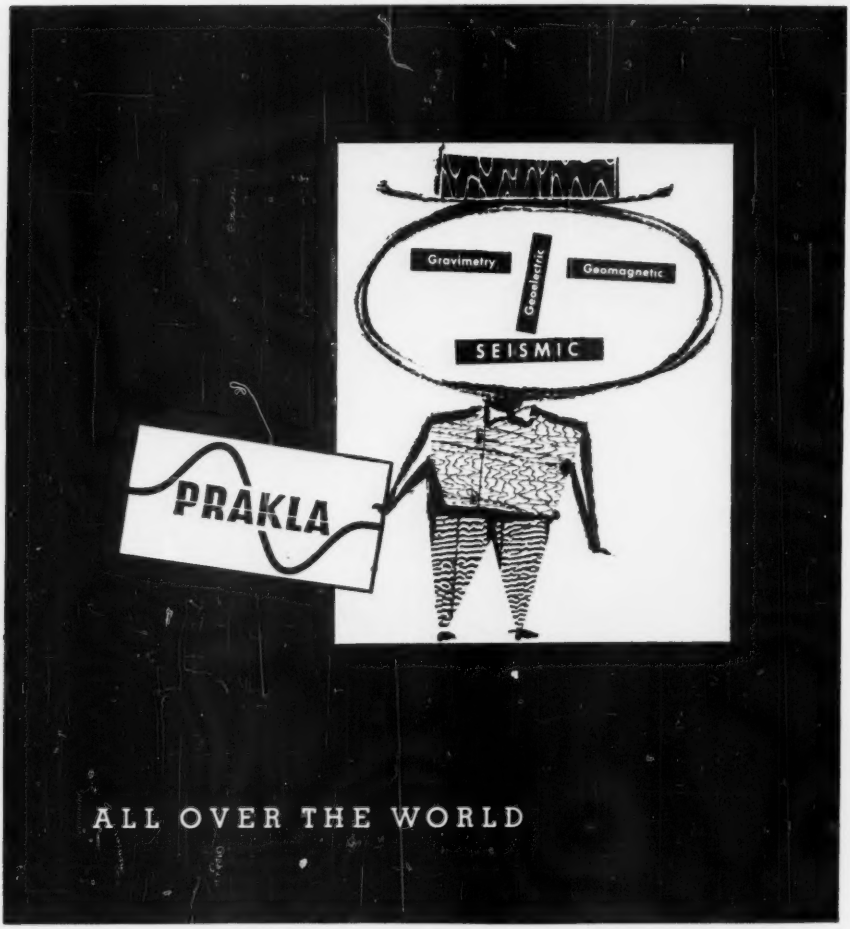


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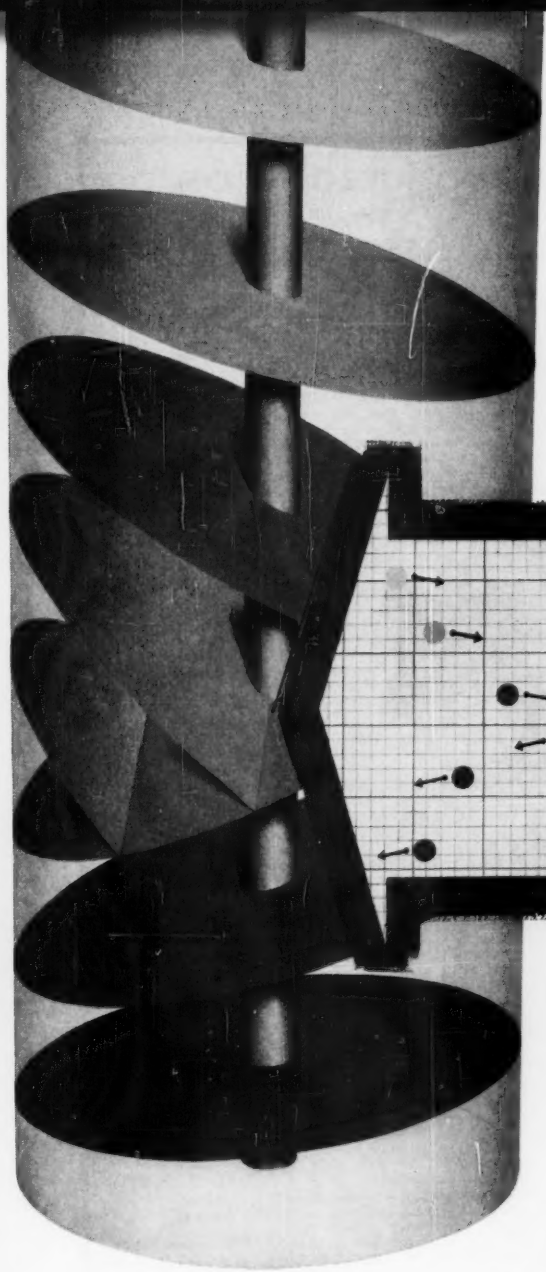

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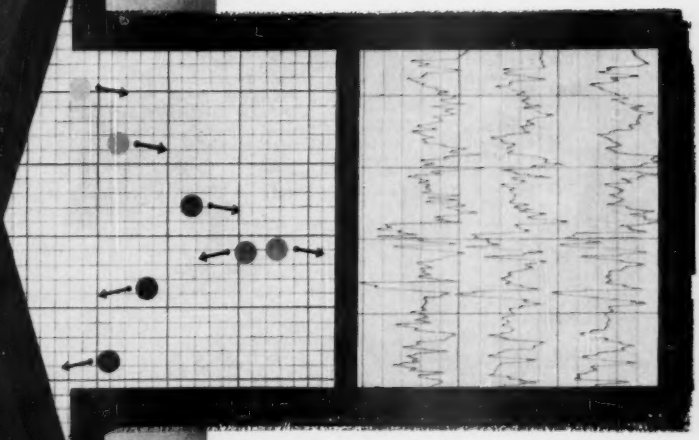

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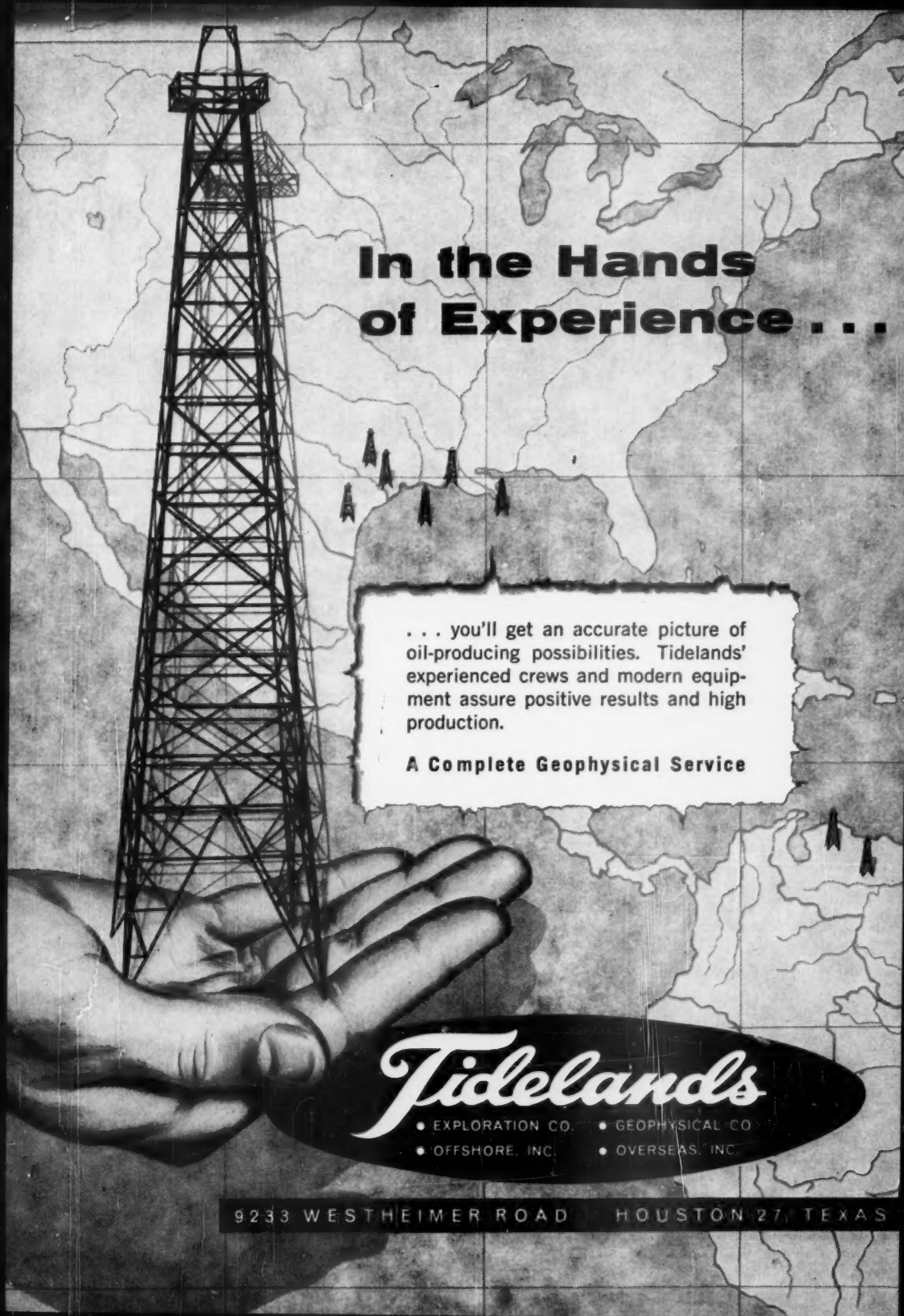
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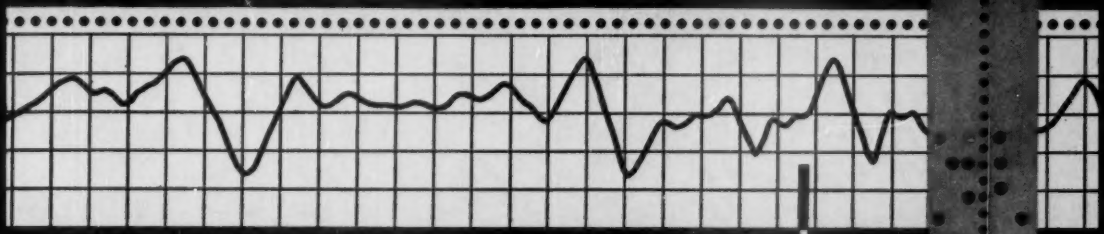

## with SSC's NEW DATA CONVERTER SERVICE

**Data recorded as curves can often be made more useful if it is converted to digital form. This is especially true where the data is to be used with electronic computers.**

**Seismograph Service Corporation now provides a complete data conversion service, at a cost far below manual conversion methods. This service includes specialists who can work with you on *any* data handling problem of this type.**

Data to be converted must be in rectangular coordinate form. The input curves are tracked by a curve follower to convert the information into electrical impulses. The final output, coded punched tape, can be fed directly into an electronic computer or translated to punched cards, or listed in tabular form. A 10-inch original curve width will convert to as many as 1000 data samples on the punched tape. The long dimension of the curve can be conformed to any one of the many scales available.

**Some examples of how this data conversion is used in geophysics: Digitized data from velocity logs are the basic raw materials used for constructing synthetic seismograms, which include multiples. Seismic record traces can be digitized for frequency analysis, auto-correlation, etc.**

**This service is available NOW. Call or write SSC today and find out how data conversion can be effectively applied to your needs.**

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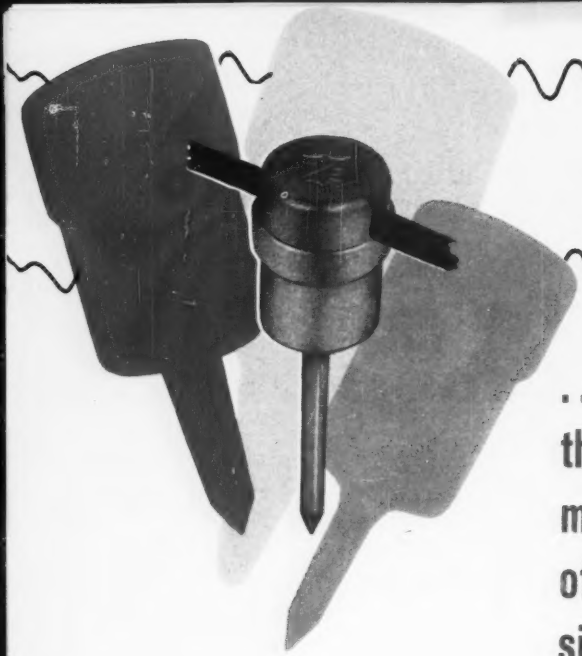


# WIGGLE FOR WIGGLE

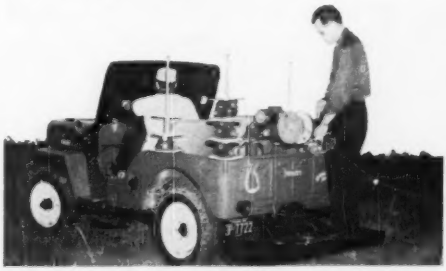
## ... trace for trace the HS-J consistently matches the performance of larger and heavier single coil geophones.

What the seismic records cannot show is the economy, efficiency and improved field techniques which the HS-J makes possible.

Why do the job the hard way when this new small geophone opens a whole new area of faster, lower cost field operations?

**ECONOMY** Remarkably low initial cost, lighter less expensive cabling, savings in crew man-hours—these are some of the reasons why more and more of the industry is turning to the HS-J.

**PORTABILITY** The HS-J's small size and light weight make the use of small hand reels and mechanical handling equipment routine procedure, speed up field work and ease the going in rugged terrain.



*Watch for exciting new automatic vehicular handling techniques, now being field tested.*

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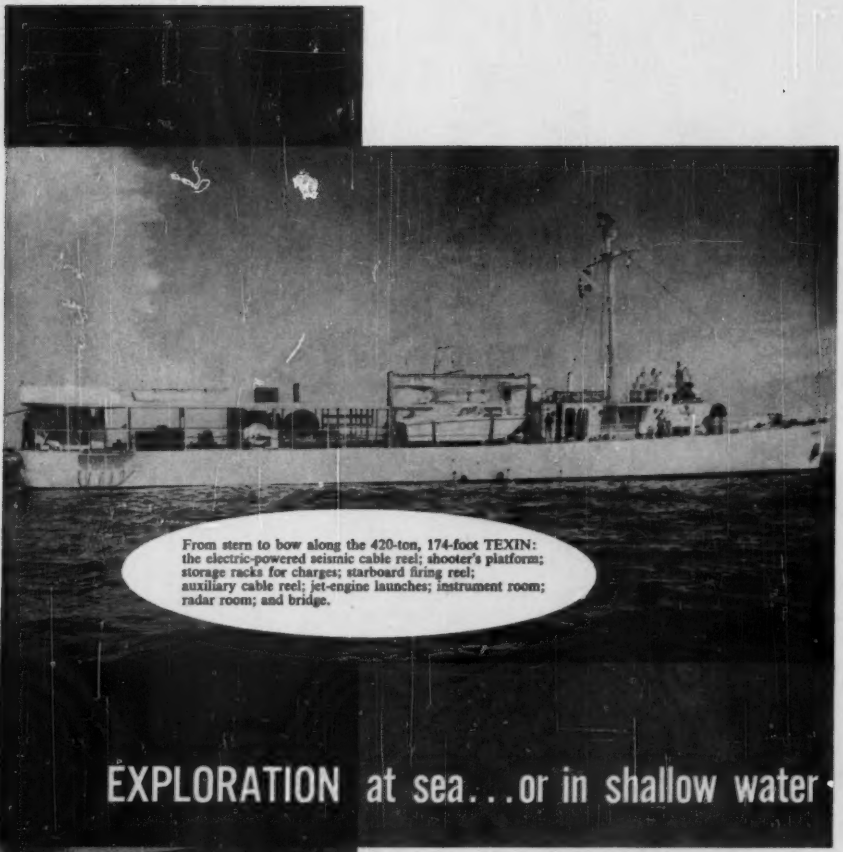

From stern to bow along the 420-ton, 174-foot TEXIN: the electric-powered seismic cable reel; shooter's platform; storage racks for charges; starboard firing reel; auxiliary cable reel; jet-engine launches; instrument room; radar room; and bridge.

# EXPLORATION at sea...or in shallow water

Remote coastal areas ... far distant from supply ports ... are the scene of many seismic surveys. These areas are best worked with the single-ship method of exploration. GSI's *new* TEXIN, similar to her sister ship the SONIC, travels to your prospect under her own power, arriving equipped and provisioned for an extensive offshore program. Auxiliary, jet-engine launches project data-gathering facilities into water no deeper than 18 inches ... giving you a complete marine survey ... from deep water to shoreline.

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